COAL BED METHANE IN THE POWDER RIVER BASIN OF MONTANA

Authors: Arthur, J. Daniel; Langhus, Bruce; Epperly, David, Bohm, Brian, Richmond, Tom, and Halvorson, Jim

J.Daniel Arthur, P.E., ALL Consulting, Tulsa, OK 74120
Bruce Langhus, Ph.D., CPG, ALL Consulting, Tulsa, OK 74120
David Epperly Ph.D., P.E., ALL Consulting, Tulsa, OK 74120
Brian Bohm, ALL Consulting, Edwardsville, IL 62025
Tom Richmond, Montana Board of Oil and Gas, Billings, MT 59620
Jim Halvorson, Montana Board of Oil and Gas, Billings, MT 59620

ABSTRACT

During the second half of the 1990s, coal bed methane (CBM) production increased dramatically nationwide to represent a significant new source of natural gas to meet ever-growing energy demands. One area that has the potential to see significant increases in CBM development in the near future is the Powder River Basin (PRB) in Montana. The PRB contains significant coal deposits with methane gas at relatively shallow depths that would allow for the economic recovery of CBM. The development of CBM in the PRB is expected to increase significantly in the coming years and with this development there is the potential for significant environmental impacts. Although significant impacts to resources will occur from surface disturbing activities during the construction phase of CBM development, these impacts can be minimized through active reclamation and following the legal guidance designed to protect resources. The primary considerations of this paper are the impacts from groundwater that is extracted to facilitate the production of methane from the coal seams. Since significant quantities of varying quality groundwater must be extracted during CBM production, the impacts of this produced water on soil, agriculture and water resources are a principle concern. The impacts from CBM produced water can be mitigated through conservation, proper disposal methods, and beneficial use. The proper management of produced water will prevent some impacts to other resources such as soil, agriculture and groundwater, and may provide beneficial uses such as dust suppression, irrigation and livestock watering.

INTRODUCTION

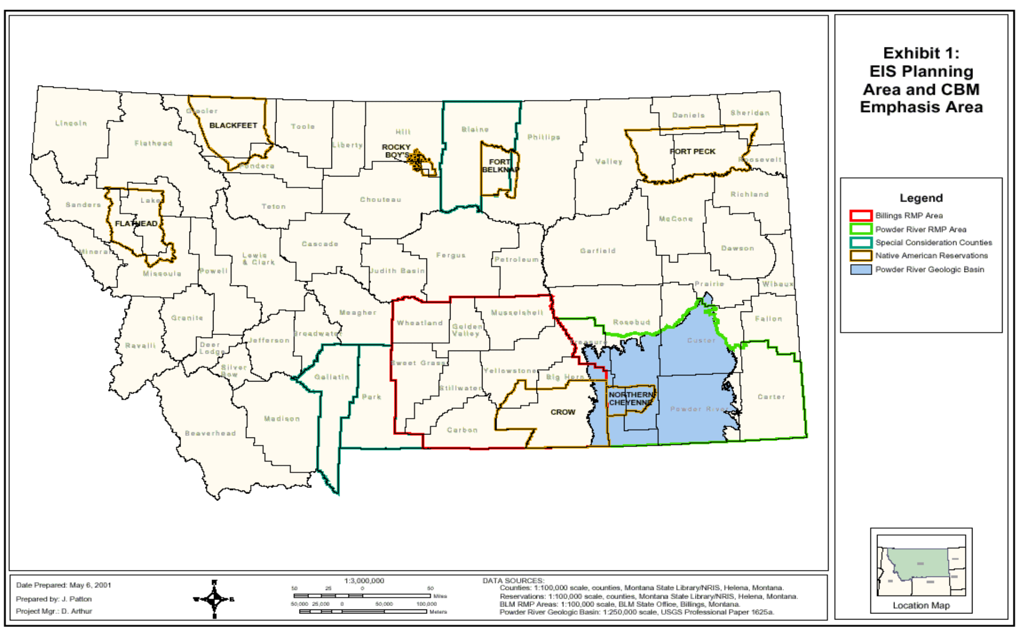
Coal bed methane is a carbon-based gas that occurs naturally in large quantities in the seams in unmined coalbeds. The coal bed methane is typically contained within the micropores of the coal and is retained in place by the pressure created by the presence of water. During production, this water is pumped to the ground surface to lower the pressure in the coalbed reservoir and to stimulate the release of methane from the coal. Methane from unmined coalbeds has been produced on a minor scale since the early 1900s when a rancher in the Powder River Basin (Wyoming) drilled a water well into a coalbed and started heating the buildings with the produced gas. Until the 1980s, coal seams generally were not considered to be a reservoir target, even though producers often drilled through coal seams when going to deeper horizons.

During the second half of the 1990s, coal bed methane (CBM) production increased dramatically nationwide to represent a significant new source of natural gas to meet ever-growing energy demands. In Montana, oil & gas development has been growing since the first oil wells were drilled in the early 20th century. Today, Montana's oil and gas industry exceeds 300 million dollars per year and is a significant aspect of the state's economic livelihood. Recent oil and gas exploration and development in the state has included a focus on CBM exploration and development. There are currently more than 200 commercially producing CBM wells in the state of Montana, all of which are located in the Powder River Basin near the town of Decker. CBM development in the Montana portion of the Powder River Basin (PRB) is in part a result of successful development in the Wyoming portion of the basin where CBM activity started as early as 1993 (Flores et al, 2001).

A primary consideration for this report is the impacts from CBM produced water on soils, agriculture and water resources. Due to the extraction methods and subsequent disposal of produced water required for CBM production, impacts can potentially result from CBM development. The purpose of this technical paper is to present the impacts from CBM.

STUDY AREA

Although a CBM emphasis area has been identified for other purposes, the primary area of concern identified for this report is the PRB of Montana. The Montana PRB is also the area where CBM development is expected to be most intense. For the purposes of this paper, analyses will primarily focus on the Montana portion of the PRB. Exhibit 1 is a map showing the entire state of Montana, the CBM emphasis area, and other points of interest for reference throughout the remainder of this paper.



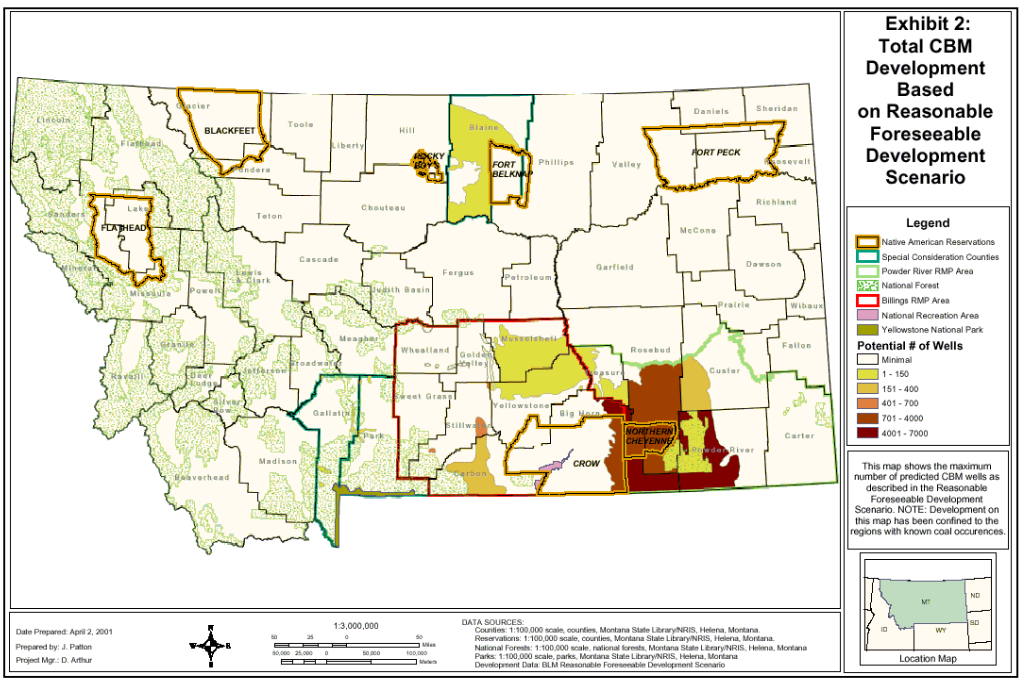
REASONABLE FORESEEABLE DEVELOPMENT SCENARIO

To facilitate planning and the determination of potential environmental consequences, the BLM prepared a Reasonable Foreseeable Development (RFD) scenario. The RFD predicts oil and gas development in five areas: the Powder River RMP area, the Billings RMP area, and in Blaine, Gallatin, and Park counties of Montana. The

RFD projects drilling of both conventional and CBM wells, numbers of pipelines, and compressors needed for production of CBM wells.

For CBM exploration and development, the areal extent of certain coals and the rank of coals in the study areas were considered. Areas of sub-bituminous to bituminous coals were considered as most likely to be explored and developed in Montana, although exploration and development has occurred mainly in sub-bituminous coal in the Wyoming portion of the Powder River Basin. The USGS produced a map showing the areas of coal, by rank, for the United States. This information indicates sub-bituminous and bituminous coals in many parts of the study area. Powder River, Rosebud, Custer, and Big Horn counties contain sub-bituminous coals in the northern part of the Basin, which extends north from Wyoming. Blaine and Musselshell counties have mostly sub-bituminous coal. Carbon County has an extension of the Big Horn Basin coal, which is ranked as bituminous coal. Gallatin and Park counties have scattered areas of bituminous to sub-bituminous coals. The projection of methane gas to be produced from coal beds in Montana range from a low of 1 TCF (Fred Crockett-PRB est-RMG, Casper) to a high of 17.7 TCF (estimated based on figures from Nelson, 2000). This and other information for Montana was used to predict where CBM exploration is most likely to occur in the emphasis area. The RFD predicts the number of CBM wells that would be drilled and completed during the next 10 to 20 years. For CBM, potential development in the RFD was estimated to be as much as approximately 26,000 wells in the next 20 years.

Exhibit 2 shows the total RFD for the CBM emphasis area, which includes the Montana portion of the PRB. Also shown on this exhibit are Native American Reservations, National Forests, National Parks, and National Recreation Areas. Review of this exhibit shows potential CBM development throughout the majority of the Montana PRB. Estimates are based on full-field development by county and shaded areas represent occurrences of sub-bituminous coals within the counties where development is likely to take place.



Analysis of the RFD with respect to the Montana portion of the PRB, suggests that approximately 4,095,000 acres of the total 5,984,000 acres that make up the PRB are expected to have CBM development. The total RFD for this area (including federal, state, and private mineral ownership) amounts to approximately 24,875 total CBM wells. Exhibit 3 illustrates the maximum potential well development as described in the RFD by watershed, shaded for coal occurrences within the basin. This exhibit shows how the predicted CBM development from the RFD intersects watersheds in the PRB of Montana. The development scenario presented in this exhibit represents total drilled wells. It is expected that about 10 percent of these wells will be dry holes.

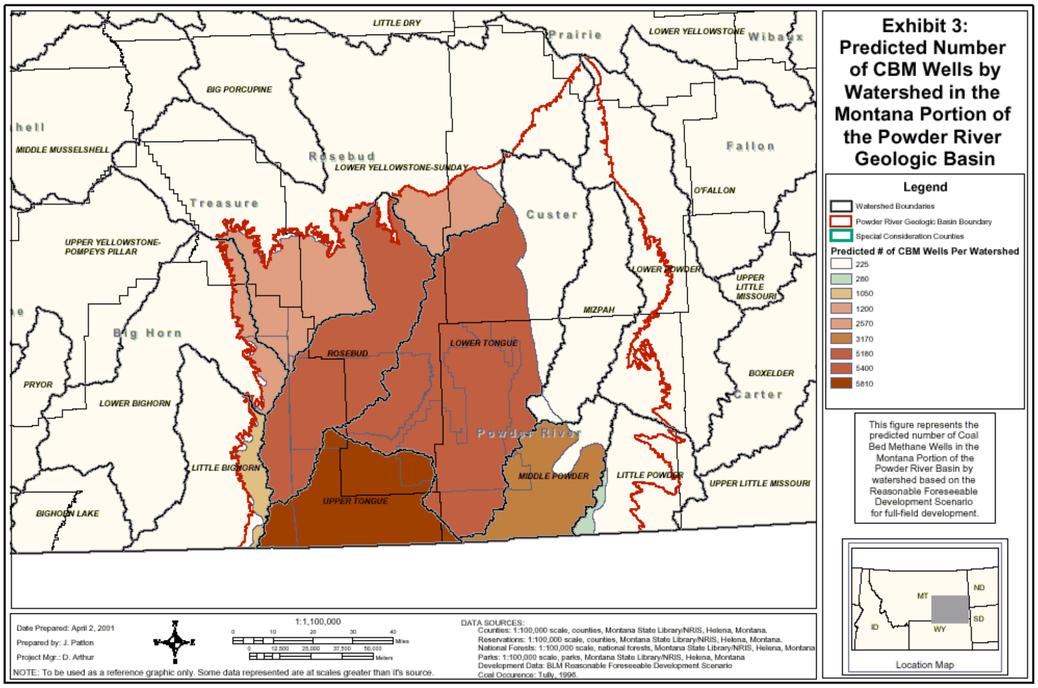


Exhibit 4 indicates the surface area of each watershed within the PRB overlying the known coal occurrences and the predicted number of maximum wells per watershed. This exhibit shows that the potential total area within each watershed that may be impacted by CBM development ranges from 24,000 acres (Mizpah watershed) to approximately 1.3 million acres (lower Tongue watershed). Similarly, CBM development ranges from high concentrations of approximately 5,809 and 5,397 in the upper Tongue and Rosebud watersheds, respectively to only 224 CBM wells in the Mizpah watershed. Considering the total RFD for the state, this exhibit shows that the vast majority of CBM development is expected to occur in the Montana portion of the PRB.

EXHIBIT 4 - WATERSHED ACREAGE AND MAXIMUM POTENTIAL CBM WELLS IN THE PRB

This table indicates the surface area of each watershed within the PRB overlying known coal occurrences and the predicted number of maximum potential wells per watershed.

WATERSHED	SURFACE ACREAGE OF IMPACTED WATERSHED	POTENTIAL WELLS DRILLED
Little Bighorn	87,000	1,050
Little Powder	29,500	278
Lower Bighorn	121,500	1,200
Lower Tongue	1,374,000	5,183
Lower Yellowstone-Sunday	687,500	2,568
Middle Powder	368,500	3,167
Mizpah	24,000	224
Rosebud	814,000	5,397
Upper Tongue	589,000	5,806
Total	**4,095,000**	**24,875**

COAL BED METHANE OPERATIONAL SUMMARY

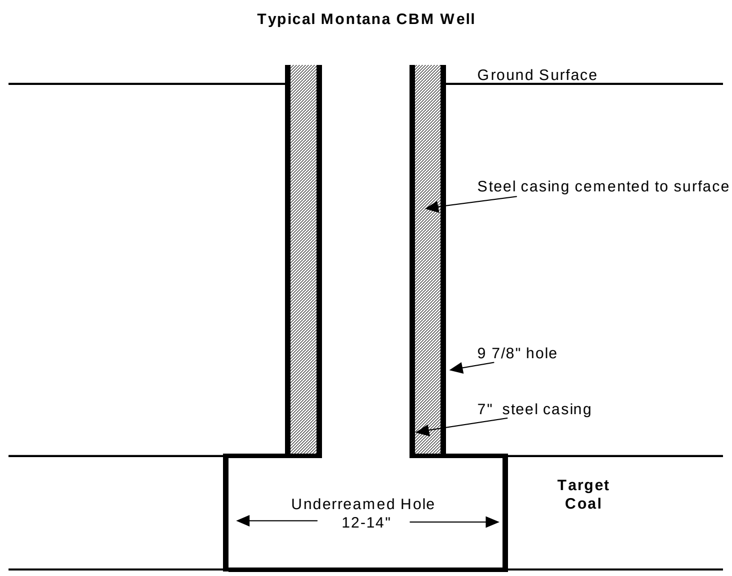
CBM has been produced in the Powder River Basin of Montana since April 1999. The first exploration wells were drilled in 1990 in both the Big Horn and Powder River Basins. The bulk of the producing data has, however, less history than that. In the CX field, operated by Fidelity Exploration & Production Company, approximately 20 months of production data have been submitted to the MBOGC.

Well Drilling and Completion

Exhibit 5 is a schematic view of a typical CBM well from the CX Ranch. This exhibit shows the more common well completion scenario where conductor casing is not used. Although there are variations in this drilling and completion methodology, the approach is generally common for current practices. However, future practices could vary from this method depending on the depth of targeted coal seams, advances in drilling technologies, or changes in drilling philosophies. Potential changes could include, but may not be limited to, completing wells in more than one coal seam or drilling directional or horizontal wells.

EXHIBIT 5 - TYPICAL CBM WELL IN THE MONTANA PORTION OF THE PRB

This exhibit diagrams a CBM well as they are typically drilled in the CX Ranch Field. In addition to the elements shown, there may be local variations.



To date, drilling has been done with fresh water drilling fluids to protect the aquifers and the coals being drilled. Water supply during the drilling phases is most often from produced water, although ponds can also be utilized. The bore-hole will finally be cleaned with a slug of formation water pumped at a high rate to flush the coalface. The wells are not artificially fractured during completion activity, although this technique may be used in other parts of the PRB or in other areas of Montana where natural fracturing (cleat) may not be developed. An electric submersible pump (ESP) is installed near the base of the coal on the end of fiberglass tubing. To help monitor the water level in the well, a 1/4-inch capillary tube may be installed for data collection purposes.

CBM PRODUCTION OPERATIONS

During production, water is pumped up a tubing string to be filtered, metered, and put into a water flow-line for handling or discharge. Many water uses and disposal methods have been suggested and could be used if CBM development continues to increase, current water handling practices are limited.

Immediately after the well is drilled, the water level stands at some elevation above the level of the coalbed, an expression of the virgin reservoir pressure. At this pressure, methane will not flow into the wellbore (Williams 2001). After initial pumping, the water level is reduced, allowing methane to flow out of the coal seam into the borehole up to the surface. The gas comes up the casing-tubing annulus and runs into a low-pressure (approximately 5 pounds per square inch [psi]) flowline. The natural gas consists of approximately 96 percent methane, 3.5 percent nitrogen, and trace amounts of carbon dioxide (CO_2). The flow-line connects to a metering manifold that knocks out the last of the water and connects to an approximately 400-horsepower (hp) field compressor that increases pressure to approximately 40 psi in a gathering pipeline. The gathering lines are connected to a large sales compressor station that builds pressure to approximately 1,000 psi in the regional sales pipeline.

Produced water is piped away from the wellsite and managed in several ways. Currently, the majority of the produced water is discharged. The discharges are permitted by the state to limit the volume of flow and specify certain discharge points, in order to control the dilution of the produced water. The permits also require that the water be discharged via a pipeline rather than a ditch, so that suspended sediments are not incorporated and do not impact the river. Part of the produced water is currently delivered to several ponds that are unlined and supply water to livestock as well as wildlife in the area.

CBM wells must pump water from the reservoir to lower pressure within the coal, to augment the formation of cleat, and to allow the natural gas to break out as a discrete phase. The amount of water that must be pumped off appears to vary not only from reservoir to reservoir, but also during the history of each individual producing well according to the specific coalbed reservoir it is producing from and its proximity to other producing wells. Exhibit 6 presents a list of the average water production rates for approximately 200 wells in the CX field normalized to the age of each well (MBOGC oil and gas database). This data was compiled by averaging the water production rates from active CBM wells from the date of first production. For example, the average for month zero was determined by averaging the water production from all wells reporting for the first time that month, regardless of the calendar date production was initiated. A similar approach was used for each consecutive month. Results from this analysis show that water production rates declined steadily at the CX Field from approximately 12 gpm to slightly less than 8 gpm over a period of 20 months.

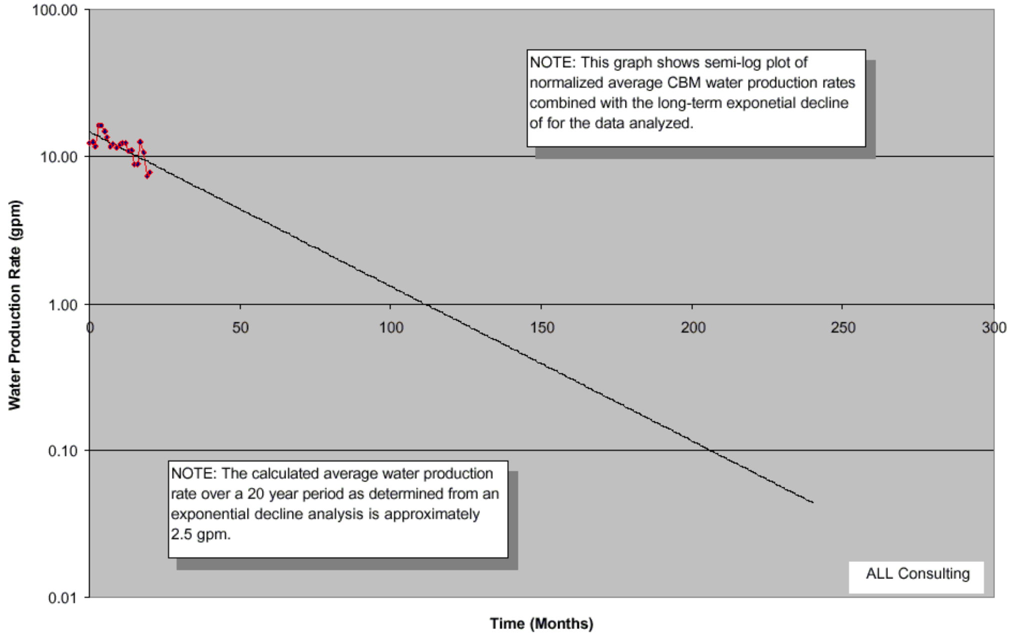
The data provided in Exhibit 6 was used to perform a water production decline analysis. Exhibit 7 shows the combined water production data and decline analysis to show a semi-log plot of normalized average CBM water production rates combined with the long-term exponential decline of the data analyzed. The projected average water production rate over a 20-year period as determined from the exponential decline analysis is approximately 2.5 gpm. The actual average water production rates for individual CBM wells may vary from this average based on location, coal seam thickness, well completion type, coal reservoir properties, and other factors. This projected average production value represents a more realistic rate calculated from historical decline rates in CBM water production.

Exhibit 6 - Average Production Rates in the CX Field, Normalized to Age of Each Well
Historical water production rates in the 200 CBM wells in the CX Field, Montana (MBOGC, April 2001).

Age in Months Since First Production	Average Water Production (BWPD)	Average Water Production (gpm)
0	418	12.2
1	428	12.5
2	398	11.6
3	553	16.1
4	556	16.2
5	503	14.7
6	460	13.4
7	398	11.6
8	412	12.0
9	394	11.5
10	411	12.0
11	427	12.4
12	419	12.2
13	375	10.9
14	376	11.0
15	303	8.8
16	305	8.9
17	430	12.5
18	367	10.7
19	253	7.4
20	267	7.8

(Notes: gpm = gallons per minute, barrel = 42 gallons, BWPD = barrels of water per day)

FIGURE 7 – PLOT OF THE COMBINED CBM PRODUCTION AND DECLINE ANALYSIS
This graph shows the average production rates at CX Ranch plotted with the decline analysis to show the average production of a CBM well over a 20-year period.



GEOLOGY AND HYDROLOGY

INTRODUCTION

Montana is the site of the juxtaposition of the Great Plains with the Rocky Mountains. The rocks at the surface vary from the ancient metamorphic and igneous complexes forming the cores of some mountains to recent sediments in the major river valleys of the state. Geology of Montana plays an indispensable role in forming the mineral resources, visual resources, and water resources of the state. The geologic history of the state has been a series of major structural events in the tectonics, or continent building of North America.

Montana's basins have accumulated sediments several miles in thickness; these sands, shales, and limestones form the source and reservoirs of Montana's fossil energy reserves – crude oil, natural gas, coal, and coal bed methane (CBM). In these basins, ancient sediments were buried to great depths within the earth where heating and increased pressure formed the fuels from the raw plant materials trapped in the sediments. The sedimentary basins also hold a significant portion of the water resources of the state; in the deep parts of these basins the water is generally salty while the shallower parts of these basins there is fresh water of meteoric origin.

Exhibit 8 presents a map of the statewide outcrop geology. The map emphasizes broad basin features underlying the Great Plains in contrast to the intensely contorted structures under the many mountain areas. These basins, such as the PRB are likely to contain CBM resources that can be seen as broad expanses of similar outcrop. In the case of the PRB, rocks at the surface are all coal-bearing Tertiary formations except for the scattered Quaternary age Alluvium in stream and river valleys. Other basins contain coal-bearing sediments of Cretaceous age. The presence of large volumes of suitable coal is vital for predicting CBM development.

CBM is the focus of this paper and it is important to recognize that the resource is intimately associated with coal deposits. The methane gas is generated by the coal deposit both under thermogenic (heat-driven) and biogenic (microbe-driven) conditions. At the same time, the methane is trapped in the coal seams by the pressure of groundwater. Releasing the pressure of groundwater from the coal aquifers liberates methane, allowing it to be produced and sold. The magnitude of the CBM resource is determined by coal type and volume; the location of coal reserves will predict the location of Montana's CBM resources.

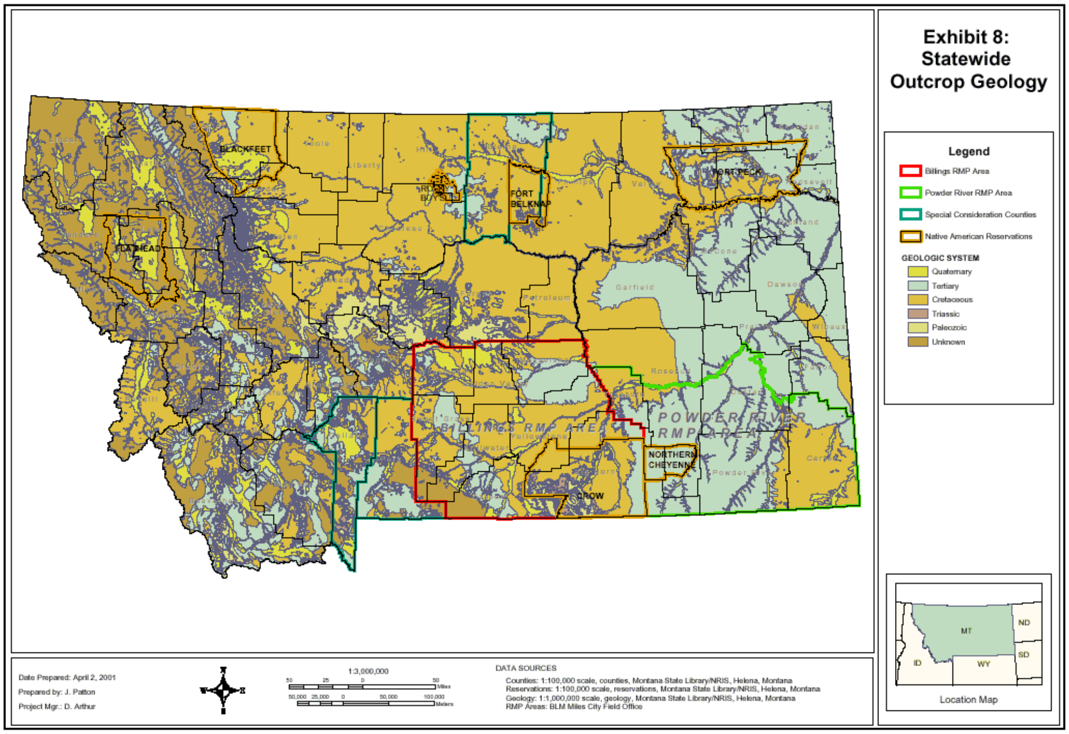
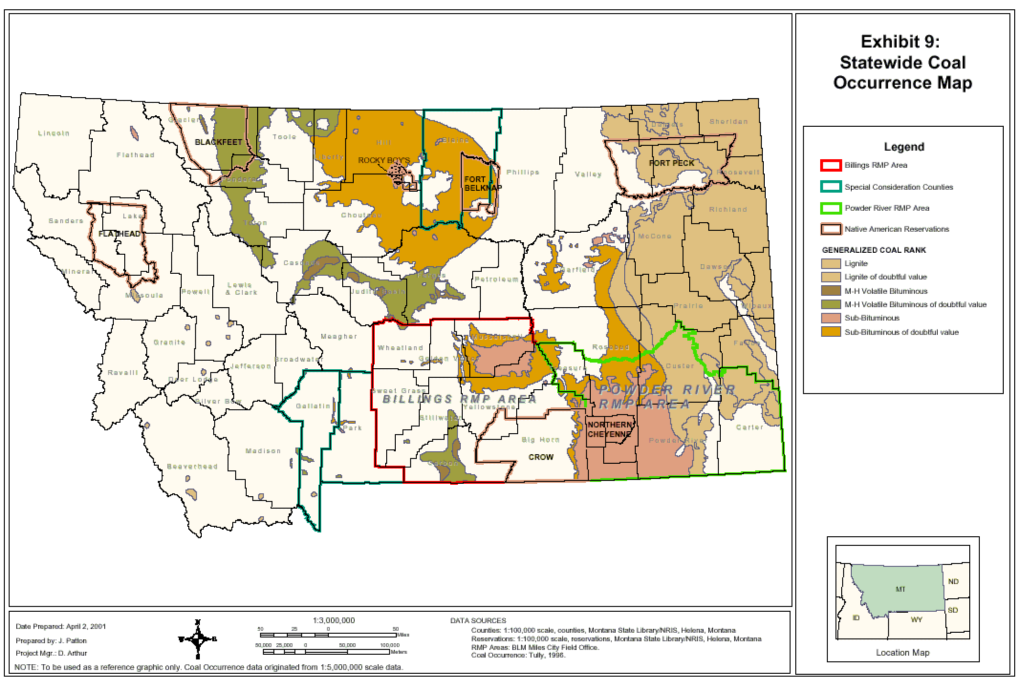


Exhibit 9 is the statewide coal occurrence map. The map displays the extent of coal deposits that support mines and are expected to support projected CBM development. The geology of Montana has given rise to several different kinds of coal; the most important differentiator is coal rank or thermal maturity. As coal is buried or otherwise heated, the raw plant material is gradually converted from complex carbon compounds to simple compounds and elemental carbon. Exhibit 9 highlights coal rank or maturation ranging from lignite, sub-bituminous, high-volatile bituminous, medium-volatile bituminous, low-volatile bituminous, and anthracite coals (Leythaeuser and Welte, 1969). The area of interest is the PRB, which contain mostly sub-bituminous coal that has not reached a high degree of maturation. Also of interest for CBM are the Big Horn Basin and the counties of Park and Gallatin that contain medium and high volatile bituminous coal of slightly higher maturity.



According to the Montana Board of Oil and Gas Conservation (MBOGC) records, CBM has been produced only in the CX Ranch field in the Montana portion of the PRB since April 1999. Exploration solely for CBM first happened in the Montana PRB in December 1990 in the area of CX Ranch. However, the first CBM exploration in the state was in August 1990 in the Big Horn Basin where CBM was tested but never sold. In many parts of the state, coals are aquifers that contain significant amounts of groundwater and are used by residents for water needs. In order to produce the methane in the Montana part of the PRB, groundwater must be drawnoff the coal aquifer. Unless groundwater is produced from the coals, methane will not be produced; water production cannot be avoided during CBM development. This is the central conflict between CBM and traditional uses of the land; when CBM is produced, local coal aquifers are partially depleted. Depending on the area, this depletion may extend beyond the CBM producing field boundaries.

REGIONAL GEOLOGY

The focus area of this paper centers on the Powder River Basin. The basin was formerly a broad shelf area until Laramide tectonics caused uplift in the surrounding features and this uplift contributed to sedimentary subsidence within the basins during the Late Cretaceous and Early Tertiary. The PRB in its entirety covers approximately 12,000 square miles with the smaller portion in Montana (Ellis et al. 1998). The PRB is bounded to the west by the Bighorn Uplift, to the southwest and south by the Casper Arch, Laramie Mountains, and Hartville Uplift; and to the east by the Black Hills Uplift. The Miles City Arch and the Cedar Creek Anticline to the north essentially separate the PRB from the Williston Basin. Coal has been mined in the PRB since 1865 and large-scale strip-mining has been underway since the mid-1960s when demand increased for relatively clean-burning coals (Flores and Bader 1999). Conventional oil and gas have been exploited in the PRB for more than 50 years while CBM has been only lately developed with major activity beginning in 1997 (Rice et al. 2000).

Exhibit 10 (formerly 11) depicts the outcrop geology of the Montana portion of the PRB. The map illustrates the broad geometry of the basin with the youngest Tertiary strata (Wasatch Formation) preserved in the deepest part of the basin just north of the Wyoming-Montana state line. The broad bands of the Tongue River and Lebo/Tullock members throughout most of the basin attest to the shallow dips to the east and north edges of the basin. The narrow outcrop bands on the west limb of the basin indicate that the basin is somewhat asymmetrical with steeper dips on the western side. Exhibit 10 also illustrates the scattered distribution of the Alluvium that fills the valleys of the basin.

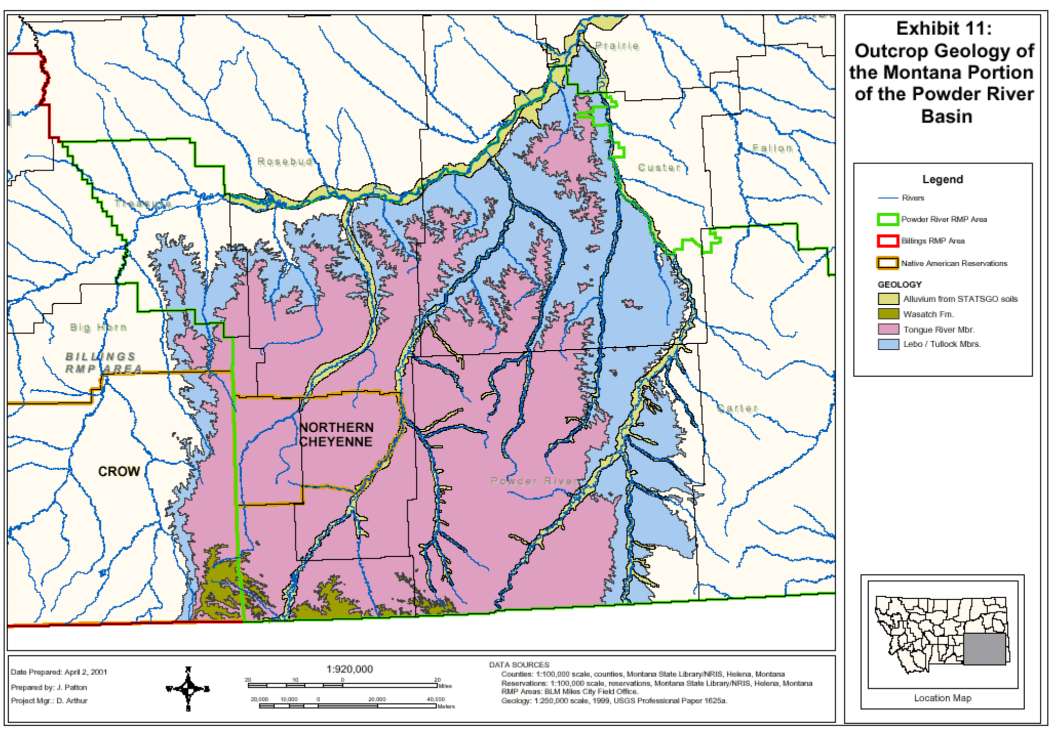
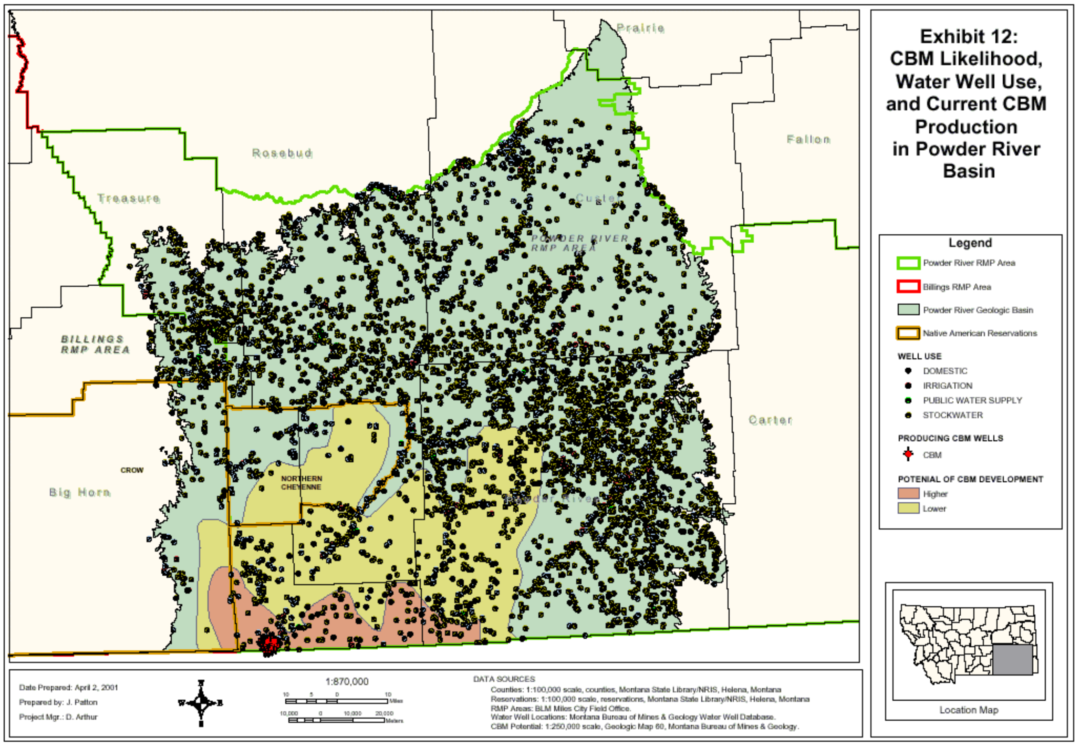


Exhibit 11 (formerly 12) portrays the distribution of water wells, the prospective CBM areas, and existing CBM production within the Montana portion of the PRB. The map was constructed from information in the MBMG

Map 60 (Van Voast and Thale, 2001) and emphasizes those areas with thick, sub-bituminous and bituminous coal reserves. Coals are both water reservoirs and gas reservoirs and as such CBM production will affect local aquifers and even surface water. CBM development is expected to be concentrated in the southern portion of the Montana PRB although coals exist over most of the basin and CBM coverage could prove to be greater. The water wells shown in the exhibit could be at risk to drawdown impact from CBM development, especially those water wells completed in coal aquifers. Those aquifers at risk to CBM impact are described in the Hydrology section below.



STRATIGRAPHY

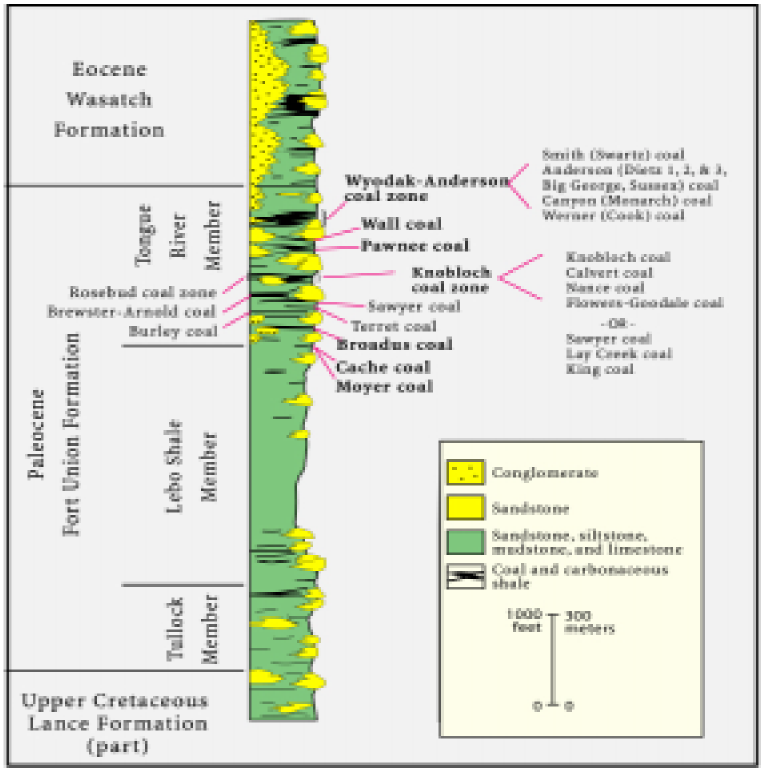
The sedimentary strata of the area extend backward in time from recent age alluvium found in stream valleys, to strata at the surface that is largely Tertiary and Cretaceous. These older sediments correspond to the Laramide tectonism that gave rise to most of the uplifted areas in Montana. Though the area contains significant regional thicknesses of older stratigraphic units, the Tertiary basin fills are of particular interest for coal, CBM, and groundwater production (Ellis et al. 1998). Conventional oil and natural gas occur in the older, pre-Laramide section but coals in the PRB are confined to the Early Tertiary units.

Exhibit 12 is a stratigraphic column of Upper Cretaceous and Lower Tertiary sediments in the Montana PRB. The stratigraphic column shows the continuous development of several thousand feet of sediments that include widespread sands, coals and fluvial, fine-grained sediments. The major formations are named along with major coal seams. The basin's surface consists largely of the several members of the Paleocene Fort Union Formation, as well as the overlying Wasatch Formation in a small corner of the basin (Rice et al. 2000).

The Fort Union Formation encloses the various coal seams within the Montana portion of the PRB; these coals function as the source of the CBM, as well as aquifers carrying groundwater of varying quantity and quality. In the PRB coals range in depth from the surface to approximately 900 feet deep. Coals vary in thickness from over 50 feet and can form aggregate thicknesses over 100 feet. Coal seams in the Fort Union do not have significant matrix porosity and permeability (Gray 1987); they can act as aquifers because fluids such as water and methane are contained within the coal's fracture system, known as cleat (Montgomery et al. 2001). The fractures accumulate the fluids and allow the fluids to move horizontally and vertically.

EXHIBIT 12 - STRATIGRAPHIC COLUMN OF UPPER CRETACEOUS AND LOWER TERTIARY SEDIMENTS IN THE POWDER RIVER BASIN

Bedrock units that fill the PRB include the Lance, Fort Union, and Wasatch Formations (Rice et al. 2000).



Paleocene Fort Union Formation

The Fort Union forms most of the sedimentary fill within the Montana PRB. It consists of approximately 3,500 feet of non-marine silty and shaley clastics and coal beds whose individual thicknesses can be as much as 37 feet near the Decker mine (Roberts et al, 1999a). The Fort Union also contains clinker deposits, formed by the natural burning of coal beds and the resultant baking or fusing of clayey strata overlying the burning coal, which are present throughout much of the area and can be more than 125 feet thick (Tudor, 1975). Stratigraphically the clinker bodies are part of the Fort Union but the clinker is a lithological unit composed of baked and fused siltstone, clay, and sandstone units that have undergone diagenetic changes during the combustion of the coal within the past 3.0 million years (**Heffern et al, 1993**).

Individual units within the Fort Union that were formed as fluvial deposits could be expected to have lithological flow-units oriented in a dip-wise fashion. This preferred direction of porosity and permeability could be exhibited by directional variations in groundwater drawdown levels. The coals, however, appear to have been deposited in mires situated above or below drainage levels within erosional channel features or perched above these channels in raised bogs (Ellis et al 1998). Some of the coals, therefore, could exhibit linear permeability phenomena while other accumulations may be isolated lenses unconnected with other coal seams. In developing CBM fields, it will be valuable to identify these different coal bodies, but such research is beyond the scope of this report.

The Fort Union is split into three stratigraphic members: the lowest being the Tullock Member, overlain by the Lebo Shale Member, overlain by the Tongue River Member (McLellan et al. 1990). In the Montana portion of the PRB, the bulk of the coals are confined to the Tongue River Member, while the Lebo and Tullock Members are predominantly shale and shaley sand (McLellan et al. 1990). The Members are discussed in detail below:

THE TULLOCK MEMBER:

This is the stratigraphically lowest part of the Fort Union, consisting of approximately 300 feet to more than 500 feet of interbedded sands and shales with minor coals near the base (Tudor 1975). The Tullock rests unconformably upon the Upper Cretaceous Hell Creek Formation throughout the PRB. While generally sandier, the Tullock is difficult to separate in outcrop and in the subsurface from the overlying Lebo Member.

THE LEBO MEMBER:

This middle member ranges from 75 feet to more than 200 feet of claystones, limestones, and mudstones with the Big Dirty coal (3 to 13 feet of thickness) at the very base (Tudor 1975). The Lebo is, in part, stratigraphically equivalent with the overlying Tongue River (McLellan et al. 1990).

THE TONGUE RIVER MEMBER:

The thickness of the Tongue River varies from 750 feet at the outcrop edge near the fringe of the basin to 3,000 feet near the axis of the basin (Williams 2001). Total coal isopach ranges up to approximately 150 feet (Ellis et al. 1999). The Tongue River Member is divided into three units. The lower unit includes that portion below the Sawyer coal seam. The Middle unit includes the Sawyer through the Wall coal seam. The Upper unit includes that portion above the Wall coal seam (Ellis et al. 1999).

The Lower Tongue River unit is present across most of the Montana portion of the basin. It includes, from the base up, the Stag, Terret, Witham, Robinson, Rosebud-McKay, Flowers-Goodale, Nance, Calvert, and Knoblach coals. In the Ashland coalfield, the Lower Tongue River unit is up to 1,660 feet in thickness, and individual coals can be up to 71 feet thick (Roberts et al. 1999b).

The Middle Tongue River unit is present over a large part of the Montana portion of the PRB. It includes, from the base up, the Sawyer, Mackin-Walker, Cache, Odell, Brewster-Arnold, Pawnee, and Wall coals.

The Upper Tongue River unit is present only in the southern part of the Montana portion of the PRB. It includes, from the base up, the Otter, Cook, Carney, Canyon, Dietz, Anderson, and Smith coals. At the Decker mine, the Upper Tongue River is up to 1,500 feet thick; coals can attain an individual thickness of 57 feet and an aggregate thickness up to 111 feet (Roberts et al. 1999a).

Although coals are the most economically significant part of the Tongue River Member, they form a small portion of the sedimentary volume. They are also extremely variable stratigraphically. Coal aquifers can be seen to have local continuity but lack regional continuity. A local coal seam such as Dietz 1 can persist for several miles but the entire Anderson-Dietz package is eroded from the Colstrip area. The stratigraphic complications documented Roberts et al (1999a) suggest that even thinly separated coal seams may be very dissimilar. These seams exhibit pinch-outs, bifurcation, and erosional cut-off by Paleocene and recent stream erosion. All of these factors can play a role in complicating the production of water and methane from the Fort Union Formation.

Fort Union coals are also present in the Big Horn Basin, the Bull Mountain Basin, and Park and Gallatin counties where they are prospective for CBM resources.

HYDROLOGY

Hydrology identifies aquifers (porous units containing water) and aquitards (non-porous strata that serve to confine and separate aquifers) in a geographic and vertical sense. Aquifers can contain drinkable water, brackish water of limited usability, or salt water. In the PRB, several formations contain drinking water but show variable reservoir quality and water quality. The Montana portion of the PRB includes many aquifers that represent different hydrologic flow regimes. The basin includes unconfined aquifers as well as confined, bedrock aquifers. Aquifers range from the unconfined Quaternary alluvium in the streambeds of rivers and creeks to the Mississippian Age Madison Formation in excess of 10,000 feet below the surface. The water quality within these aquifers ranges from less than 300 mg/L TDS to more than 30,000 mg/L TDS (Bergantino 1980). The aquifers also vary in depth from the basin center to the margin. Coal aquifers are widespread, supply large numbers of water wells, and will be impacted most by CBM production.

Exhibit 13 lists the significant aquifers in the Montana portion of the PRB. The wells are almost exclusively completed in the shallow aquifers (< 500 ft depth) with the Tongue River Coals being the major aquifers. Wells completed in the major aquifers are limited in geographic distribution – Alluvium wells are distributed along principle rivers and streams, coal wells are arrayed in two principal bands corresponding to two stratigraphic packages, and Cretaceous sand wells are largely limited to the rim of the PRB. Only a very few wells utilize the Wasatch Formation, an aquifer that is more widespread and more important in the southern part of the PRB. A small number of wells near the edges of the PRB use the Cretaceous aquifers. A few wells utilize the sands in the Lebo and Tullock Members. The majority of water wells are completed in the Tongue River coals. The coal aquifers are the most important to this report since they hold the CBM resource and production of the gas will directly impact coal seam aquifers. CBM production inevitably impacts coal seam aquifers within and around CBM producing fields. CBM production may also impact Alluvium aquifers where they intersect impacted coal seams.

EXHIBIT 13 - AQUIFERS IN THE MONTANA PORTION OF THE PRB

Summary of Montana PRB aquifers and associated data for approximate depth and number of current wells listed in the MBMG database.

AGE	AQUIFER	APPROXIMATE DEPTH	NUMBER OF WELLS IN THE MBMG DATABASE
Quaternary and Recent	Quaternary Alluvium	Surface to 90 feet	198
Tertiary	Wasatch	100 feet	6
	Tongue River Coals	50 to 400 feet	957
	Lebo/Tulloch	100 to 400 feet	306
Cretaceous	Hell Creek/Fox Hills	100 to 500 feet	199
	Judith River	2500 feet	1
	Eagle	2700 to 5700 feet	0
	Dakota/Lakota	5600 to 8600 feet	0

Note: MBMG = Montana Bureau of Mines and Geology

Dakota/Lakota Formation

This formation is present at approximately 5,600 feet bgs in the northern part of the PRB and at approximately 8,900 feet bgs at the southern Montana state line. The Dakota is present across the basin and commonly contains more than 50 feet of sand.

Eagle Formation

This sand zone is present at the south edge of the Montana portion of the PRB at approximately 5,700 feet bgs and at approximately 2,700 feet bgs on the northern edge of the basin. The Eagle exhibits scattered sand development. In Gallatin, Park, and Blaine counties, the Eagle Formation contains coal seams; in these counties CBM production may impact the Eagle sand aquifers.

Judith River Formation

This formation shows in excess of 40 feet of total sand at a depth of approximately 2,150 feet bgs near the Ashland coal area at the northern edge of the PRB. Sand in this formation is not present everywhere and produces water of only moderate quality; water of this quality could not be used for drinking or irrigation without treatment.

Fox Hills—Hell Creek Formations

These Cretaceous sands combine to form the principal aquifer in southeastern Montana (Miller 1981). Water wells into the joined sands can yield as much as 40 gpm. Municipal supply wells can yield more than 200 gpm (Miller 1981). Water quality is generally lower than in either the Fort Union or Quaternary Alluvium. The Fox Hills/Hell Creek aquifer is separated from the coal aquifers in the Fort Union by over 500 feet of fine-grained sediments in the Tullock and Lebo Members; these aquitards are not penetrated by CBM development wells and will, therefore, maintain their integrity. CBM production and drawdown of coal aquifers will not impact water wells using these Cretaceous or deeper aquifers.

Fort Union Formation

The Fort Union Formation contains minor sands and all of the water producing coal beds in the Montana PRB. Coal beds are the most-used aquifers in the Montana PRB (MBMG 2001) where they are largely used for stock watering. Yields can be as high as 150 gpm but average approximately 10 gpm (Bergantino 1980). Within the PRB, coalbed water wells are often less than 100 feet deep but can be as deep as approximately 400 feet (MBMG 2001). Coal reservoir parameters are listed in Exhibit 14 below. The thickness information provided appears to be highly variable but this may not be the truth; previous analysis may have combined thinner coal seams that are separated by thin shale layers that form local aquitards, but appear to be minor lenses in cores or wire-line logs. Porosity data is largely a measure of fracture porosity that is notoriously difficult to measure. The other parameters listed are also dependent upon fracture or cleat density. A more basic uncertainty is the unknown influence of coal bed methane on reservoir characteristics – is there a genetic connection between reservoir parameters and the presence of significant quantities of methane? Do the same coal seams, in a non-producing condition, have significantly different characteristics? There is insufficient data in the Montana portion of the PRB to provide answers. CBM produced water will be discussed in more detail within the impacts chapter of this Technical Report.

EXHIBIT 14 - PUBLISHED RESERVOIR PARAMETERS FOR ACTUAL AND POTENTIAL CBM RESERVOIRS

Reservoir parameters for several coal bed aquifers throughout the Montana portion of the PRB as compared to the Wyodak-Anderson Wyoming EIS data.

COAL SEAM	THICKNESS	TRANS-MISSIVITY	HYDR. COND.	POROSITY (%)	STORAGE COEFF.
Anderson – Dietz (CX Ranch) Redstone 1999	70’	300 ft^2/day	3.37 ft/day	2.0	2.18E-5
Knobloch (Montco Mine, permitted but not opened) (MDSL, 1982)	44’	58 ft^2/day	2.3 ft/ day	2.0	1.2E-4
Knobloch (Ashland Mine, not permitted) (Woessner, et al, 1981. EPA-600-7-81-004a.)	54’	100 ft^2/day	2 ft/day	2.0	5.0E-5
Wyodak-Anderson (BLM, 1999a) For comparison only	Variable		2.0E-5 m/sec (5.67 ft/day)	1.0	1.0E-4

Groundwater conditions described for the Montana Portion of the PRB Resource Management Area (RMA) also exist within the Bull Mountains Basin in the Billings RMP area (Noble et al. 1982). In this basin, Quaternary Alluvium and shallow Fort Union Formation coal and sand aquifers are important sources of water. Coals in the Billings RMP area are adjacent to sand aquifers and are aquifers themselves; water production from Bull Mountains Basin coals is likely to cause drawdown to nearby water wells similar to the Montana portion of the PRB in addition to possibly impacting vertically adjacent aquifers.

Wasatch Formation

Only a very small portion of the Montana PRB contains Wasatch bedrock; the formation has been either eroded or was not deposited over most of the area except within the very center of the basin. In the Wyoming portion of the PRB, Wasatch sands are significant aquifers that can support wells that yield in excess of 500 gpm (BLM 1999b).

Quaternary Alluvium and Associated Terrace Deposits

These clastic sediments are unconfined and in connection with permanent or significant ephemeral rivers and streams. Thickness can exceed 90 feet, but most average less than 30 feet (Bergantino 1980). Water yields average 25 gpm, but can be considerably higher (Bergantino 1980). Quaternary alluvium is the most-used aquifer in the Great Plains portion of Montana (Noble et al. 1982). In the Montana PRB, a total of 198 wells are identified as being screened in the Quaternary Alluvium (MBMG 2001). These wells are largely used for domestic supply, but are also used for publicly owned water systems, livestock, and irrigation. In the Montana PRB, Fort Union Formation coals outcrop in the valleys of streams and are in contact with alluvium. At the edge of the basin, Lebo and Tullock aquifers, as well as Cretaceous aquifers, outcrop in streambeds.

The coal aquifers are of special interest since they hold the CBM resource and production of the gas will directly impact coal seam aquifers. CBM production inevitably impacts coal seam aquifers. CBM production may also impact Alluvium aquifers where they intersect coal seams. The most important groundwater-surface water interaction concerning the effects of CBM production is the exchange of water between coal seams and surface water via Alluvium. Several bands of coal seam development – Anderson, Knoblock, and Colstrip – outcrop as clinker in the watersheds of major streams. These clinkers often give rise to springs that feed into rivers and alluvium. During periods of little run off, such as late winter when streams and rivers are at baseflow, streams are particularly vulnerable to impact from surface recharge by low quality coal aquifer water. At times of high run off, rivers and streams often have sufficient flow to dilute the coal aquifer water coming via clinker-fed springs.

WATERSHEDS

Watersheds are important to predicting the impacts from CBM development in Montana. Water resource factors such as water quality, water use, and potential impacts will be discussed throughout this report in terms of watersheds. Each watershed is drained by a single stream or river and each is bounded by a no-flow topographic boundary. Streams and rivers are profoundly influenced by their watersheds; in particular water volume and water quality vary from base flow conditions to high-flow conditions under the control of runoff from land surfaces and recharge to rivers by aquifers. Exhibit 3 highlights the watersheds in the PRB along with potential CBM areas. The areas of highest potential for CBM development fall within the northern portion of the Upper Tongue River Watershed, the southern section of the Lower Tongue River Watershed, the western section of the Middle Powder River Watershed, and the eastern section of the Rosebud Watershed. The current CBM production area in the Montana PRB lies within the Upper Tongue River Watershed. It should be noted that the watersheds along the southern boundary of the Montana PRB drain to the north and may already be impacted by CBM development in Wyoming.

IMPACTS FROM CBM

INTRODUCTION

This chapter presents an overview of the environmental impacts from CBM production in the Powder River Basin. The descriptions of predicted effects that would result from the exploration, construction, operation and maintenance, and abandonment activities associated with CBM are compared to the pre-project environment. The method of recognizing impacts and accomplishing a systematic impact analysis are in accordance with the Council on Environmental Quality guidelines, which institutes procedures on applying NEPA. The duration of the impacts are analyzed and described as either short-term (up to 5 years) or long-term (life of the project and beyond). Mitigation measures that are not already included as part of the project are described and evaluated, and the residual impacts are determined. Physical impacts to landscapes from development disturbances can easily be quantified, however, effects to watersheds or wildlife can not easily be distinguished and therefore are discussed in conjunction.

IMPACTS AND ENVIRONMENTAL CONSEQUENCES

The development of CBM resources will produce environmental impacts resulting from the exploration, construction, and operations and maintenance activities associated with CBM when compared to the current environment. Areas of concern such as water, air quality, soil, cultural, paleontological, geologic and mineral, and agricultural resources were identified during public scoping as being potentially impacted. There were also concerns that impacts to areas such as the socio-economics of the region, the climate, Indian Trust Assets, Recreation areas, visual resources, wilderness study areas, and the land use and realty would occur. The impacts to these resources may be either positive, negative, or in some cases both, with some areas experiencing more impact than others. The areas of particular interest are those with the highest potential impacts from CBM development such as water resources, soil, and agriculture. These areas will be discussed in greater detail than other areas where less impact is expected.

The level of disturbance for installation and production of a single CBM was determined in order to facilitate some uniformity in impact analysis. A breakdown of the level of disturbance was calculated for a single CBM well for exploration, construction and operation, these disturbances would be 1, 3.25, and 2.0 acres/well respectively. The level of disturbance is less for exploration wells since no permanent structures will be constructed. The operation disturbance is less than the construction disturbance since areas will be immediately restored as they become unnecessary. Although quantitative impacts can be determined for some resources, qualitative impacts were determined for others. A brief discussion of the impacts to all resources will be discussed later in this report.

Resource Specific Impacts

AIR QUALITY

Air emissions would be caused by short-term activities such as construction-generated dust, vehicle and exhaust emissions, natural gas venting during drilling and testing of the well, and accidental releases of gas during drilling and pipeline transport. Air quality issues would also arise from long term activities such as the operation of large central compressor stations used to transport methane gas from production areas and from diesel generator operations used to power the well stations.

CULTURAL AND PALEONTOLOGICAL RESOURCES

Cultural and paleontolgical resources are potentially impacted by surface and subsurface disturbing activities. Activities that involve the use of heavy equipment (road construction, well drilling, pad construction, pipeline and utility placement, etc.) and which result in changes to the natural landscape cause the most disturbance and have the greatest effect on cultural and paleontological resources. Other activities, such as increased travel and vandalism resulting from access improvements, and increased erosion resulting from surface disturbances, can also impact these resources. These activities can also produce indirect impacts to the resources such as fires; hazardous waste spills and cleanups; changes in livestock grazing patterns; and wildlife habitats.

ENVIRONMENTAL JUSTICE AND INDIAN TRUST

Environmental justice is a measure to ensure that there is fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development of environmental regulations and policies. Environmental justice is important to CBM development in the PRB of Montana because the development area includes three Indian reservations with substantial minority (Native American) populations. The development area also includes several counties with elevated poverty rates. The level of CBM development will determine to some extent the degree to which environmental justice will be impacted. Impacts to groundwater resources from drawdown, air quality from emissions, and surface water quality for discharge would be widespread and would affect the Indian reservations and poverty stricken counties.

GEOLOGY AND MINERAL RESOURCES

The production or drainage of oil and gas including CBM results in the irreversible and irretrievable loss of these resources. One such loss would result from mineral drainage to adjacent leases from the production of hydrocarbons including the drainage of CBM resources in Montana from production in Wyoming**.** Wells placed in proximity to mineral lease boundaries would drain neighboring mineral leases. Other activities such as venting or flaring natural gas beyond emergencies, well evaluation, or initial testing would also represent drainage and waste of mineral resources. Another drainage issue results from produced water associated with CBM production that may or may not be an irreversible or irretrievable loss of resources depending on the water quality and aquifer from which it is drawn.

Other impacts of CBM development include the prevention of conventional oil and gas development, coal mining, and surface mineral mining because of surface facilities and producing wells on CBM sites. Other impacts to coal mining include CBM production dewatering at nearby coal seams, which can cause underground coal fires, methane seeps, and the liberation of methane to water wells.

LANDS AND REALTY

Potential land use impacts would primarily consist of conflicts between CBM activities and other uses of property, such as agriculture and residences. New realty authorizations for gathering lines and power lines, for example, would impact rights-of-way (ROWs) and land segmenting. The development of CBM resources impacts agricultural production by taking land out of production and by soil contamination from drilling and production activities.

Short-term impacts of land uses during construction would consist of the physical intrusion by CBM crews and equipment, the local generation of dust and noise, and the limited obstruction of traffic. Long-term impacts include loss of existing land use, increased access from roads, and loss of land value.

Some surface landowners are unaware of the severed mineral rights, and even though compensated, they would be displeased with the possibility of having well facilities located near dwellings. Placement of roads and well pads near residential, business, and community dwellings may cause direct reductions of property values. Impacts from placement of roads, utility lines, and well pads around communities may cause loss of future community development opportunities.

SOCIAL AND ECONOMIC VALUES

Impacts on social conditions would include changes in employment and population; changes in the services provided by local governments; the effects of drilling and related activities on rural lifestyles in the project area; the effects of changes in employment opportunities on communities; and the effects of population change on local housing and services.

Direct economic impacts of the project would include changes in personal income resulting from new employment of CBM workers; purchases of equipment, supplies, and services from local area vendors; lease, royalty, and production payments; taxes and other government levies; and related changes in the fiscal health of local governments. Indirect impacts would include induced economic activity from local purchases of equipment, supplies, and services; induced economic activity from purchases of goods and services by project workers; and changes in the sources of income for local governments.

WILDLIFE

CBM exploration and production includes development of roads, pads, power lines, utility corridors, and facilities as well as human activities and regular human presence. Much of this activity would occur in the relatively undisturbed native short grass prairie of eastern Montana, resulting in both direct and indirect impacts on wildlife. Those impacts would be localized around CBM exploration and production sites and proportional to the level of activity at a particular location.

Direct habitat loss and direct and indirect impacts because of habitat disruption and wildlife disturbance caused by roads and utility corridors would cause the bulk of the impacts on wildlife. Direct impacts on wildlife would also include mortality as relatively less mobile small mammals, reptiles, and amphibians are killed during road and other site construction during development of CBM facilities. Additional direct impacts that may occur on private lands include greater potential loss of riparian vegetation and other floodplain habitats valuable for wildlife, abandonment of raptor nests because of direct habitat loss and disturbance, and habitat loss for a wide range of species in prairie dog towns larger than 80 acres.

Indirect impacts of road development and use during exploration and production on wildlife and wildlife habitat include biological effects, such as displacement and stress, habitat fragmentation, abandonment of habitat features, physiological penalties from unnecessary energy expenditure in response to vehicles, and other effects related to changes in hunting opportunity (Bury 1980; Trombulak and Frissell 2000, USDI and USDA 2001).

Overhead power lines constructed for production wells pose problems for a variety of wildlife species. Raptors and other species of birds occasionally collide with power lines, especially during periods of relatively poor visibility. Another wildlife disturbance factor associated with CBM exploration, development, and operation is noise. Noise effects would likely be greatest during exploration and development, but would continue through production and abandonment.

WATER RESOURCES IMPACT ISSUES

Introduction

The production of coal bed methane (CBM) has the potential to impact water resources in a variety of ways. Drawdown of coal seam aquifers is an unavoidable impact because the de-pressurization of coal seams is inherent to the process of CBM production. Once brought to the surface during production operations, produced water is essentially a waste bi-product that must be disposed of. Options for disposal include discharge to land or surface water bodies, re-injection, or one of many beneficial use options (e.g., stock watering, controlled irrigation, dust control, storage impoundments, etc.).

The combination of potentially substantial water volumes combined with relatively poor to moderate water quality characteristics emphasizes the needs to closely evaluate and monitor CBM development and production. Depending on the area, groundwater and/or surface waters may vary in potential vulnerability. To fully understand these potential vulnerabilities and impacts, analysis of both groundwater and surface water is required.

GROUNDWATER DRAWDOWN

Groundwater drawdown from CBM production has been documented inside and adjacent to existing production in Montana. CBM production in the PRB requires drawdown of coal aquifers within the producing field in order to liberate methane. Water wells adjacent to but outside of a producing CBM field may also be adversely impacted. Drawdown can be documented by way of dedicated monitoring wells or by gauging private water wells. In Montana's CX Ranch CBM field, the MBMG has installed monitoring wells designed to track drawdown due to the coal mines in the area as well as CBM development.

Exhibit 15 (formerly 21) is a location map of monitoring wells, CBM wells, and coal mines near Decker, Montana. This exhibit shows the spatial relationship between monitoring stations and both coal mine development and active CBM production at the CX Ranch field. Both water level and water quality data have been collected at the monitoring wells identified, although some are currently inoperative. Some of these monitoring wells are periodically checked and sampled. Monitoring data for these wells were obtained from the Montana Bureau of Mines and Geology.

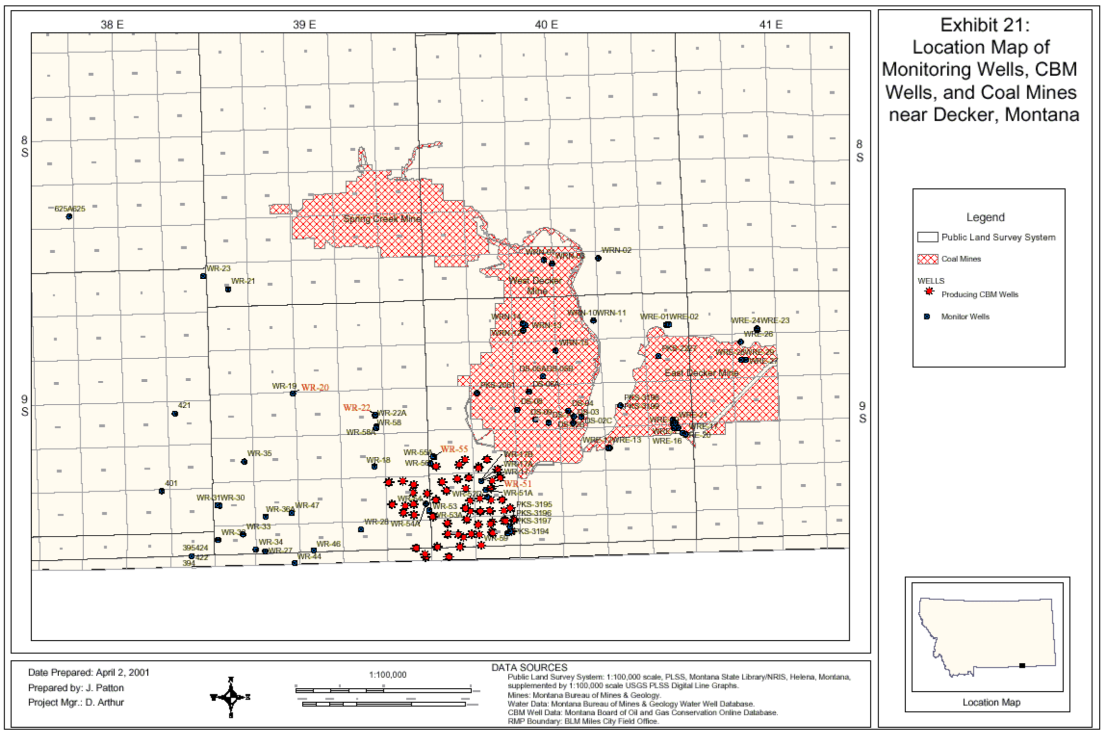


Exhibit 16 summarizes the water level data of 14 monitoring wells in or adjacent to the CX field for which coal aquifer data is available. Those wells closest to the center of CBM development tend to show drawdown at the earliest date, however there are exceptions. The degree of draw-down recorded appears to be due to water production from the nearly 200 CBM wells now on-line at the CX field as summarized above; production began with the drilling of the first CBM wells in March 1998 and first pumping in December 1998 (Williams 2001).

It is unclear what the limit of drawdown will be as the field continues to produce CBM. It may be that as pumping rates drop in the CX Ranch Field, the drawdown radius of impact may cease spreading and may stabilize.

The CX Ranch is still being developed and producing wells are being added. Full extent of CBM development and full extent of offsite aquifer drawdown cannot be estimated at the present time. It is possible that if further development doesn't take place, the WR-22 well may not be drawn down beyond its present point. It is also possible that if more CBM wells are drilled, then WR-22 may be surrounded by CBM wells and drawdown will likely increase more rapidly.

Groundwater drawdown can result in wide-ranging methane migration phenomena under adjacent leases including methane liberation into in nearby water wells, coal fires, etc. have been observed in other coal basins. The PRB is sufficiently different from the San Juan Basin (SJB); however, it may not support methane migration away from aquifer drawdown. Methane liberation into non-produced water wells has been demonstrated at CX Ranch, the extent of the phenomenon is unknown at the present time.

EXHIBIT 16 - SUMMARY OF WATER LEVEL DATA FROM CX FIELD MONITORING WELLS
Statistics on the13 hydrographs in the vicinity of CX Ranch CBM Field

MONITORING WELL	DISTANCE FROM NEAREST CBM WELL	DATE OF ONSET OF DRAW-DOWN	TIME FOR DRAW-DOWN TO REACH WELL	MAXIMUM DRAW-DOWN
WR-17	0.0 miles	10/1999	11 months	21 feet
WR-51	0.0 miles	1/1999	1 month	111 feet
WR-53	0.0 miles	10/1999	11 months	74 feet
WR-53A	0.0 miles	11/2000	24 months	2.0 feet
WR-54	0.0 miles	10/1999	11 months	38 feet
WR-55	0.2 miles	11/1999	12 months	51 feet
WR-28	0.92 miles	None	-	0.0 feet
WR-22	1.8 miles	3/2000	16 months	10 feet
DS-05A	2.40 miles	None	-	0.0 feet
WR-27	3.12 miles	None	-	0.0 feet
WR-19	3.68 miles	None	-	0.0 feet
WR-20	3.68 miles	None	-	0.0 feet
WRE-10	4.20 miles	None	-	0.0 feet

The San Juan Basin (SJB) has experienced gas seeps and coal fires that appear to be increasing in number in concert with increasing CBM production (BLM, 2000b). It is hypothesized that nearby CBM production has intensified seep activity. Specifically, lowering of the water table in the monocline by downdip dewatering of coal beds is postulated to allow CBM to desorb from coal beds near the outcrop. The desorbed gas could then migrate buoyantly updip to the outcrop and seep. The details of this potential process are not well understood at this time.

Heffern (1999), as quoted in the WYODAK Draft EIS (BLM, 1999c), compares the characteristics of the SJB of southwest Colorado and northwest New Mexico, with its coal fires, methane seeps, and high temperatures that have killed vegetation, with the PRB to evaluate the potential for coal fires and methane migration or seepage within the PRB. Although some similarities exist between the two basins, there are significant differences.

1. Basin pressurization and regional groundwater flow – the PRB is not an overpressured basin, as is the SJB. Groundwater flow in the PRB coal aquifer is downdip, toward the center of the basin (USGS, 1986b), rather than updip toward the outcrop.

2. Recharge from clinker - Unlike the SJB where there is little groundwater recharge or clinker at the coal outcrop, extensive deposits of porous clinker occurring in the PRB near the coal mines trap rainfall and snowmelt and recharge the coal aquifers (USGS, 1988; Peacock et al 1997).

3. Coal characteristics - The bituminous coal in the SJB, while having less volatile matter, has developed better cleat and fractures than the sub-bituminous coal in the PRB. Due to its cleat, the SJB coal must be completely dewatered to achieve maximum production. The methane in the SJB is largely thermogenic, generated at depth from the high temperatures and pressures associated with burial. In the PRB, the methane is biogenic, and water is retained in the cell structure of the coal. In the PRB, overpumping of water from the coal could shut off methane flow if the cell structure collapses, rather than releasing methane (Selvig and Olde, 1953).

4. Basin structure - In the SJB outcrop area, where methane seepage occurs, it is confined to a much smaller area. Therefore, methane seepage may be more concentrated in the SJB than in the PRB. The SJB also is more highly deformed than the PRB and contains more faults and fractures that could serve as conduits for methane migration. Aubrey, et al. (1998) also notes the lack of substantial caprock in the SJB that would limit the flow of groundwater or methane migration.

5. Experience in existing mines - Mine fires are common in piles of coal fines and along the highwall in PRB mines, and are regularly extinguished. Since CBM development began, mine inspectors have not noted a significant increase or decrease in the number of fires in coal pits located east of the Marquiss and

Lighthouse CBM projects where, to date, groundwater drawdown due to CBM development has been greatest. Moreover, the frequency of coal fires in these pits is similar to that for coal pits located some distance from CBM development.

Methane seepage can occur naturally in the vicinity of near-surface coal seams (Glass et al., 1987 and Jones et al., 1987). The potential for methane migration within the PRB is not limited to areas containing near-surface coal seams or areas where CBM drawdown has occurred. Methane migration potentially could occur at widespread locations within the PRB, as methane can migrate long distances along naturally occurring joints or fractures in rocks. Whether methane migration occurs in the PRB and whether methane seepage could accelerate the natural process of coal combustion is an unresolved question.

GROUNDWATER BALANCE

Groundwater resources can be balanced against current groundwater production and projected CBM water production within watersheds of the PRB. Exhibit 17 represents a calculated estimate of the water resources that exist in the coal seams of the Montana portion of the PRB. The estimate utilizes the acres within each watershed that have known coal occurrences that could be utilized for CBM development from Exhibit 3. Each acreage figure is multiplied by an average coal thickness of 70 feet from USGS Prof. Paper 1625-A. This is a volume figure that can be used with a porosity estimate (2%) to derive a total in-place groundwater volume for each watershed. These figures add up to an estimated 249.73 billion cu ft of groundwater for the projected CBM area of the PRB. This total does not include the volume of all the coal seams in the PRB, instead only those coals in the CBM potential development area. This total does not include waters held in non-coal aquifers.

EXHIBIT 17 - TOTAL GROUNDWATER RESOURCES IN THE COAL SEAMS OF THE MONTANA PRB WATERSHEDS

Calculated estimate of the water resources that exist in the coal seams of the Montana PRB

WATERSHED	TOTAL ACRES OF WATERSHED	TOTAL GROUNDWATER RESOURCE OF WATERSHED (Billion cu ft)	WATERSHED	TOTAL ACRES OF WATERSHED	TOTAL GROUNDWATER RESOURCE OF WATERSHED (Billion cu ft)
Little Big Horn	87,000	5	Middle Powder	368,500	22.5
Little Powder	29,500	2	Mizpah	24,000	1.5
Lower Bighorn	121,500	7.5	Rosebud	81,4000	49.5
Lower Tongue	1,374,000	84	Upper Tongue	589,000	34
Lower Yellowstone-Sunday	687,500	42	**TOTAL**	**4,095,000**	**248**

Exhibit 18 shows a calculation of the potential water production resulting from the maximum number of CBM wells (from the RFD) for each PRB watershed per year. The average water production rate was calculated from an exponential trend analysis and the details can be seen in Figure 7. The table illustrates that the watersheds with the greatest water production are those with the most wells, i.e. Lower Tongue River, Upper Tongue River and Rosebud. The total water production for all CBM wells in all the watersheds is 4.4 billion cu. ft. per year or approximately 1.75 percent of the water in the coal seems of the Montana PRB Watersheds.

EXHIBIT 18 - MAXIMUM POTENTIAL PRODUCED CBM WATER BY MT PRB WATERSHEDS

Calculation of the potential water production resulting from the maximum number of CBM wells from the RFD full-field scenario for each PRB watershed per year.

WATERSHED	EFFECTIVE ACRES (Acres)	MAX POTENTIAL PRODUCING WELLS	AVERAGE WATER PRODUCTION RATE PER WELL (gpm)	MAX POTENTIAL PRODUCED CBM WATER PER YEAR (Billion cu ft)
Little Big Horn	87,179	1,050	2.5	0.184
Little Powder	29,605	278	2.5	0.049
Lower Bighorn	121,538	1,200	2.5	0.211
Lower Tongue	1,374,159	5,183	2.5	0.910
Lower Yellowstone- Sunday	687,303	2,568	2.5	0.451
Middle Powder	368,349	3,167	2.5	0.556
Mizpah	23,941	224	2.5	0.039
Rosebud	813951	5397	2.5	0.948
Upper Tongue	589009	5806	2.5	1.020
TOTAL	**4,095,034**	**24,873**	**2.5**	**4.4**

SURFACE WATER IMPACT FROM DISCHARGE

Impacts to surface water from discharge of CBM water can be severe depending upon the quality of the CBM water. Some watersheds may be able to absorb the discharged water while others are sensitive to large amounts of low-quality CBM water. Water quality data is from stream gauging points maintained by the USGS. These multi-year collections of water quality data illustrate changes within the stream from times of high run-off (typically June for the PRB) when the river is the highest and water is mostly the result of precipitation from spring rains and melting snow. During periods of high flow the streams and rivers contain higher quality water. The USGS data also contains data on base-flow conditions (typically winter in the PRB) when streams are at their lowest flow and water quality is the lowest since much of the water is recharge from alluvial and bedrock aquifers where groundwater is often of low quality. Water quality data consisting of stream flow and SAR is analyzed for a number of USGS gauging points to worst case conditions for CBM water discharge. In addition to surface water information, projected CBM water discharge data is analyzed for comparison; the quality of discharge water is estimated to be the same as produced water from the CX Ranch field, SAR = 47. It is likely however that some of the coal aquifers contain water that differs from the CX Ranch produced waters.

Produced CBM water can have impacts on surface water if it is discharged directly to streams and rivers. In a highest impact scenario, all the water produced in the projected CBM wells would be discharged to the primary drainage in each watershed. The results of this scenario are tabulated in Exhibit 19. In this table, the existing drainage way conditions are compared to the worst case conditions for CBM discharge. If the worst-case scenario would develop – 100% of the CBM produced water would be discharged at the gauging point during the average base-flow conditions. The resultant SAR values are a weighted average of the maximum CBM discharge and the average base-flow. Again for this scenario water quality was assumed to match that of CX Ranch. The biggest impacts would be those streams with low flow volumes and low SAR values such as Rosebud (near Kirby) that have a substantial increase in flow from the CBM discharge waters. In the case of Rosebud (near Kirby) the SAR increases from 0.8 to 44.4 and has an increase in flow from 1.78 cfs to 31.78 cfs.

EXHIBIT 19 - WORST-CASE DISCHARGE SCENARIO – BY WATERSHED – USING CX RANCH WATER QUALITY

Highest impact scenario for Montana PRB as tabulated from CX Ranch quality water for primary drainage in each watershed.

Watershed	Base Flow (cfs)		SAR		High Flow (cfs)	
	Existing	Potential	Existing	Potential	Existing	Potential
Little Big Horn (Near Wyola)	61.8	67.6	1.2	5.1	526	531.8
Little Big Horn (near Crow Agency)	123	128.8	NA	NA	782	787.8
Little Big Horn (near Hardin)	138	144.8	2.0	3.8	851	856.8
Little Yellowstone-Sunday (Myers)	4200	4214.3	1.7	1.9	42,000	42,014.3
Little Yellowstone-Sunday (Hysham)	0.01	14.31	8.5	47	280	294.3
Little Yellowstone-Sunday (Colstrip)	0.6	14.9	4.5	45	65	79.3
Little Powder (near Broadus)	0.35	1.90	NA	NA	69	70.55
Lower Bighorn (near St Xavier)	1750	1756.7	2.5	2.7	10,300	10,306.7
Lower Bighorn (near Big Horn)	640	646.7	3.7	4.1	21,500	21,506.7
Mizpah (near Mizpah)	26	27.25	21.0	21.4	60.1	61.35
Middle Powder (near Moorhead)	153	179.5	5.2	6.1	1433	1450.5
Middle Powder (near Broadus)	198	224.5	NA	NA	1077	1094.5
Rosebud (at Reservation Boundary near Kirby)	1.78	31.78	0.8	44.4	15.7	45.7
Rosebud (near Colstrip)	7.5	37.5	1.5	37.9	56.5	86.5
Rosebud (at mouth near Rosebud)	9.02	39.02	3.7	37	77.0	107
Upper Tongue (at state line)	181	213.3	NA	NA	1724	1746.3
Upper Tongue (at Tongue R. Dam near Decker)	175	207.3	1.1	8.25	1467	1489.3
Lower Tongue (near Birney Day School)	185	213.9	1.4	7.6	1202	1230.9
Lower Tongue (near Ashland)	206	234.9	NA	NA	2073	2101.9
Lower Tongue (at Miles City)	194	222.9	2.4	7.1	1305	1333.9

Except for the Little Big Horn and the Mizpah watersheds, the worst-case discharge would have unacceptable impacts on stream conditions. For both the Little Big Horn and Mizpah, the number of wells is expected to be so small that discharge volumes are also expected to be small and dilution will be sufficient to avoid any significant degradation to water in terms of SAR. Other streams and rivers cannot withstand the maximum discharge of

CBM water; the calculated resultant water would be unusable for irrigation. This statement is based upon the maximum number of CBM wells as computed by the RFD and the potential CBM map as well as the assumption that produced water will be the same quality as CX Ranch water. If CBM produced water is less sodic than the CX Ranch water and closer to river water in quality, watersheds will be able to accept more CBM discharge. As discharge waters increase in volume, however, there is the potential to impact riparian areas via increased erosion and sediment transport. Exhibit 19 also casts watershed flow rates against worst-case discharge rates at each potential discharge point. Increases caused by discharge range from approximately 0.1% if all 5,183 CBM wells discharge into the Lower Tongue near Ashland, Montana up to 191% if all 1250 CBM wells discharge into the Rosebud near Kirby, Montana. For the former, little erosion would be expected while for the latter, significant impact could be expected if riparian areas were prone to erosion**.**

AGRICULTURAL IMPACTS

Impacts to agricultural systems, and to other aspects of the land resource, are evaluated in this section. It should be noted that for this analysis it has been conservatively assumed that undiluted CBM water will be used year-round. The low rates of flow from most CBM wells would likely permit the blended or intermittent use of CBM water, which could reduce or eliminate the level of impacts suggested in this analysis. The use of CBM water for irrigation will also be limited to the growing season for the intended crops, which usually ranges from 100 to 150 days per year.

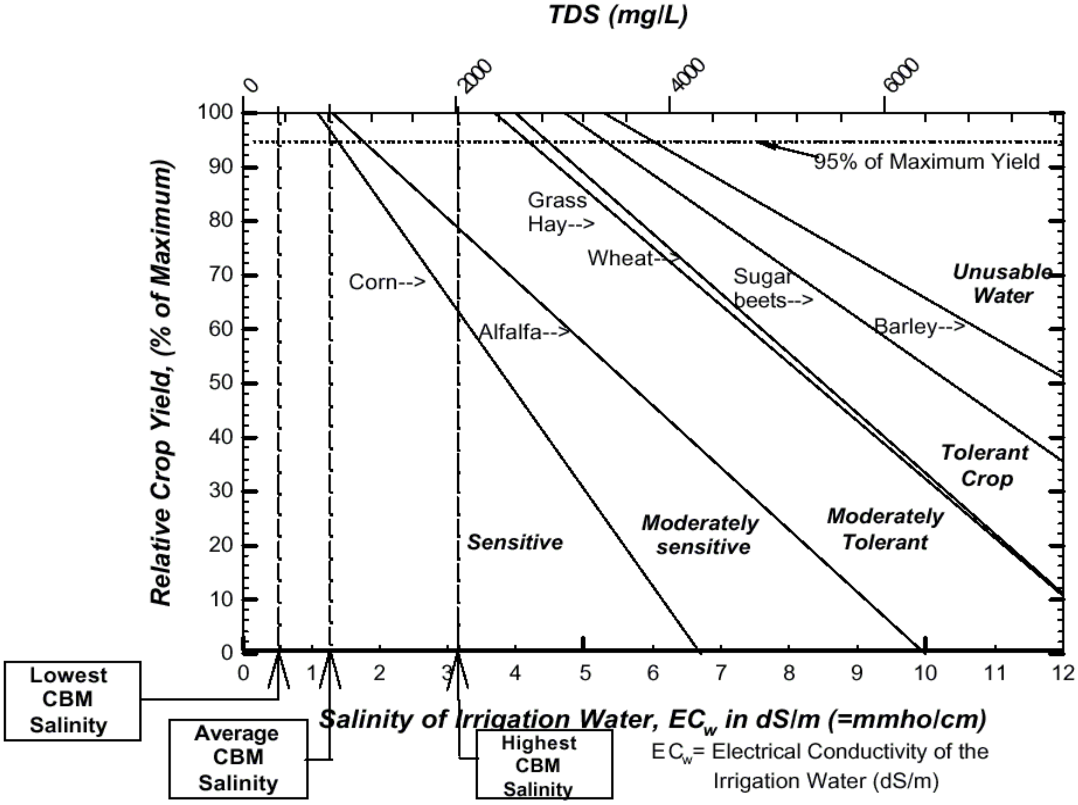
Agricultural Irrigation

Potential impacts from agricultural irrigation with CBM water are related to the quality of the water. To determine these impacts, the quality characteristics of the CBM water can be compared to generally accepted irrigation water quality requirements (Ayers and Westcot 1985). The quality categories are discussed and compared to the previously presented CBM water quality characteristics as follows:

> **Salinity** *(affects crop water availabilit*y): The principal measure of salinity of irrigation water is EC expressed in deciSiemens per meter (dS/m). (Note: 1 dS/m = 1 mmhos/cm). Crops vary in their response to irrigation water salinity as follows:
>
> ?? < 0.7 dS/m — provides no restrictions to crop growth
> ?? 0.7 – 3.0 dS/m — provides slight to moderate restrictions to crop growth
> ?? > 3.0 dS/m — provides severe restrictions to crop growth
>
> The lowest, mean (average), median, and highest salinities of the CBM water are 0.47, 1.3, 1.13, and 3.02 dS/m, respectively. From Exhibit 3, the average salinity of the CBM water from the 19 Decker wells is 2.39 dS/m. Based on these values, CBM water with salinities equal to those of the indicated lowest and average salinities would pose no significant problem even for most sensitive crops. CBM water with the highest indicated salinity may pose problems only to some moderately sensitive to moderately tolerant crops.

The tolerances to salinity of six example crops grown in the study area are shown in Exhibit 22. In developing the basic data used for Exhibit 22, Ayers and Wescott (1985) assumed a leaching fraction of 15 percent to 20 percent. The line indicating 95 percent of potential yield is also shown. Since the basic data are somewhat empirical, and since many other elements of the crop environment can also affect yield, it is considered reasonable that comparisons can, from a practical standpoint, be made using this indicated level of yield as a no-impact point. It is doubtful that such a yield decrement could be detected as attributed only to the level of salinity in the soil. Also from a practical standpoint, it is likely that farmers will alter their management practices (i.e., ensuring adequate leaching or selecting appropriate crop cultivars) to fit the specific conditions that occur to maximize the crop yield.

Exhibit 22. Relationship Between Relative Crop Yield and Irrigation Water Salinity for Six Sample Crops



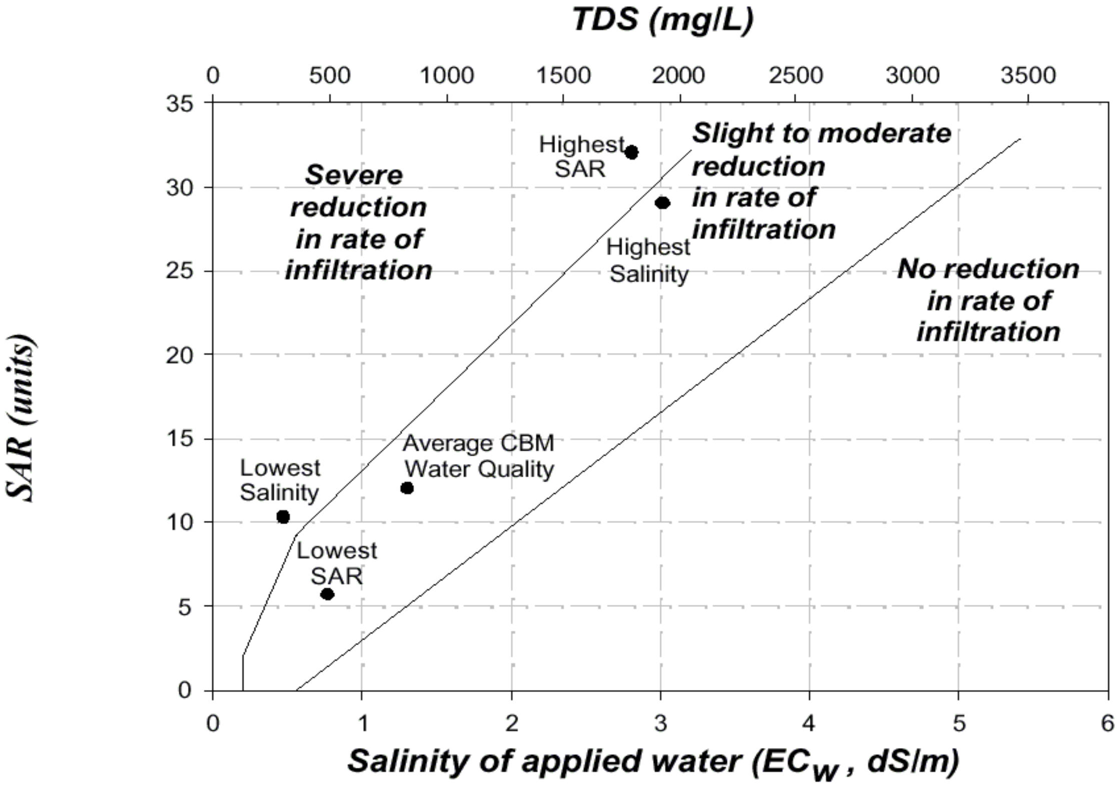
Source of basic data and original graphic:
Ayers R.S., and D.S. Wescott. 1985. Water Quality for Agriculture FAO Paper 29.
Tanji K.K. 1990. Agricultural Salinity Assessment and Management, ASCE Manual No. 71.
Shannon M.. 1996. Personal Communications. U.S. Salinity Laboratory, USDA, Agricultural Research Service, Riverside, CA.

With normally accepted management practices, the lowest CBM water salinity would have no adverse effect on the example crops. For the more salinity-sensitive of the example crops, such as alfalfa and corn, the salinity level of the average CBM water is near the threshold of causing yield reduction, and care would have to be taken to ensure adequate leaching. Also, a portion of the irrigation water supply may have to come from other sources, probably current irrigation water sources. From the standpoint of salinity, the other example crops should do well with any of the indicated CBM water as a sole source for irrigation, provided the soil has good internal drainage and normally acceptable management practices are followed. Prospective irrigators should be provided with this information in order for them to make the decision if they can accept a possible yield reduction, or possible increase in the case where a crop goes from dryland to irrigated.

SAR (Sodicity) *(affects infiltration rate of wate*r): Generally, increasing levels of SAR create an increasing hazard for infiltration problems. However, if the irrigation water contains higher levels of salinity, the SAR can increase without greatly increasing the infiltration hazard. Therefore, both the SAR and the EC of the irrigation water are used to evaluate potential infiltration problems. Usually, SAR values below 3.0 are not considered to be a threat to crops and native plants; however, SAR values above 12.0 are considered sodic and may affect soils and vegetation.

Exhibit 23 shows the potential infiltration hazard of the average CBM water quality. Such water may cause a slight to moderate reduction of the rate of infiltration of water into the soil. Also shown in Exhibit 23 are the individual CBM waters (Rice et al, 2000) with the lowest and highest salinity (EC) with their corresponding SAR, and those with the lowest and highest SAR and their corresponding EC. The individual waters with the highest SAR and lowest EC could cause a significant reduction in the infiltration rate if the waters were used continuously as the only water supply. The individual waters with the lowest SAR and the highest EC would likely cause only a slight to moderate reduction in the infiltration rate of the soil.

Exhibit 23. General CBM Water Quality Relative to the Potential for Dispersion of Soil Aggregates and Reductions in Soil Rate of Infiltration (Based on data from Ayers and Westcot 1985)



Trace Elements *(affects crop toxicity)*: Certain trace elements in the irrigation water can cause toxicity in certain crops. Ayers and Westcot (1985) present recommended maximum concentrations of trace elements in irrigation water. A comparison of these recommended maximum concentrations to the highest concentrations presented in Exhibit 24 showed that, in every case, the highest concentrations of the CBM waters were considerably lower, in most instances by one to three orders of magnitude, than the recommended maximums.

Livestock Watering

As with plants, certain trace elements in drinking water can be toxic to livestock. Ayers and Westcot (1985) present water quality guidelines for livestock. A comparison of these water quality guidelines to the highest concentrations of the CBM waters and the average concentrations of the CBM water indicated that all of the CBM waters would be very satisfactory to excellent for use as livestock drinking water. In some cases, the water could cause temporary diarrhea in livestock not accustomed to such water, but this problem should rapidly disappear as animals adapt to the new water supply.

OTHER IMPACTS

In addition to supplying water to plants or livestock, landspreading or surface discharge of the CBM water can cause undesirable impacts. Where irrigation water is otherwise unavailable or not supplied, discharge of CBM water to land would have the benefit of providing water for plant growth. With the higher salinity CBM waters shown in Exhibit 23, long-term landspreading would likely increase the salinity and sodicity of the affected surface soils and hence adversely affect the native vegetation and wildlife habitat. This could lead to an increase in primary productivity of plant communities adapted to this new hydrologic condition or changes in the existing plant community in response to the new hydrologic regime. Resulting communities and habitat would necessarily be adapted to the quality of water from the specific CBM source wells. This could lead to subsequent changes in the wildlife community to one adapted to salt-tolerant plant communities. Accumulation of evaporated salts could also occur in any closed depressions, which would destroy vegetation in these depressions. Such long-term discharge to the land surface could also cause excessive erosion of the soil and gullying, which could intensify over time if high SAR water reduced infiltration. With long-term discharge of high salt CBM water to constructed evaporation ponds, removal and disposal of the accumulated salts would likely be required.

With discharge of the CBM water to surface drainageways and streams, serious erosion could occur damaging or destroying instream vegetation (Bauder 1999). The erosion can result in increased sediment loads, which along with the potential high salinity and sodicity, can significantly degrade the stream and receiving water quality. This degraded quality could also affect the biological aspects of the stream. It is also important to note that, depending on the quantity and level of quality of the discharged CBM water, the receiving waters could significantly dilute the concentrations of the constituents in the CBM water, resulting in potentially minimal impact from salinity on the receiving waters. Of course this would depend on the amount of CBM water released in relation to the flow in the receiving water bodies. Bauder (1999) presented a scenario based on the assumption that 100 CBM wells producing 10 gallons per minute (gpm) each for a total of 2.2 cubic feet per second (cfs) were discharging into the Tongue River near Decker, Montana. The mean flow of the river at the lowest period is about 180 cfs, and during the high flow it is about 1,680 cfs. In terms of volume of water, the CBM water discharges are likely to be insignificant compared to the normal flows of the Tongue River. On the other extreme, the RFD produced by the Miles City, Montana BLM in 2001 gives the full field development of a maximum of 26,000 wells in the next 20 years. At an average flow of 10 gpm per CBM well, this would be approximately 580 cfs (1,150 ac-ft/day), which could make a significant impact on the environment.

The construction and continued use of the CBM wells and gas production facilities, the network of roads and pipelines, and storage ponds can cause significant impacts to the local resources. The actual surface disturbances and use of the facilities can cause erosion of the soils and introduction of noxious weeds to the surrounding area. The existence of the facilities reduces the forage base for livestock and wildlife. The activities during use of the facilities can also adversely affect the activities of the various native wildlife species.

LONG TERM EFFECTS

The long-term impacts of using CBM water or diluted discharge water for agricultural purposes include crop effects, farming practice changes, irrigation management, and direct effects to soils. However, with proper crop selection and appropriate irrigation management, economic yields can be sustained under low to moderate saline conditions.

The use of high salinity/sodium CBM water may have long-term effects on crops. There may be limitations on which crops species can viably be grown. More salt tolerant crops may have to be grown where higher salinity irrigation water is used, such as barley and sugar beets, as well as hays such as Bermuda, wheatgrass and wildrye, instead of the more salt sensitive plants like wheat, alfalfa, corn, and clover hay. Some crops may show toxic effects of salts accumulating in the leaves or rootstock over time. This is most common in trees and other woody perennials.

Another long-term effect of using high salinity CBM water may lead to the modification of cropping practices. This may include such practices as modifying seed placement (e.g., planting on furrow sides, double-row raised beds, increasing seeding rates, etc.) to achieve better germination and stands; new or modified equipment for crop sowing; growing different crops; soil profile modification for better drainage and water penetration; and the use of amendments such as gypsum or sulfur to soils to improve water permeability lost to excess sodium in the soil.

Soils do not usually become excessively saline from use of saline water in a single irrigation season, depending on the quality of water used. It may even take several irrigation seasons to affect the level of salt in the soil solution. The maximum soil salinity in the root zone that results from continuous irrigation with saline water does not occur when salty water is used only a fraction of the time. Changes may need to be made to irrigation water management techniques required to use CBM water. The method of application of irrigation water may need to change. A real application with sprinkler irrigation can cause concentrated salt accumulations near the soil surface and cause foliar damage to certain plants. Other types of application such as drip and furrow irrigation have less salt accumulation at the soil surface in the shorter term, but still may result in salt accumulations in deeper soils over the longer term. Additional irrigation water will be required for leaching to ensure salts are moved out of root zone. Increasing the frequency of irrigation may also need to be implemented to maintain soil water content and decrease the effects of applying saline water (less water holding capacity and higher salinity levels). These increases in irrigation water amounts may lead to producers having to file for additional water rights or finding other sources of lower salinity water for leaching, and a potential for more saline seeps in areas irrigated with CBM water.

The cumulative effects of the application of high SAR CBM water to the soil and the build up of sodium will have an affect on the physical characteristics of the soils -which in turn affect the chemical characteristics – and then the biological characteristics. It is possible to create a site through sodium saturation which will not support the production of very many plant species. This is not so much a consequence of the sodium as it is a consequence of the externalities, i.e., the things that come about when the soil is saturates with sodic water and it disperses (deflocculates). This includes a shut down of the water and gas exchange processes. The soil is likely to go from and aerobic situation to an anaerobic (oxygen devoid) system. High SAR/sodic water should not be applied to fine textured, slow infiltration, poorly drained soils. This would include silts, clays, silt loams, silty clay loams, clay loams, sandy clays. These soils are dependent on good structure for infiltration. If sodic water is applied to these soils, the probability of soil dispersion (deflocculation) is high. Once the soil disperses, infiltration and drainage decrease. The long-term consequence is an anaerobic, waterlogged, saline/sodic soil. These soils can be reclaimed, but the requirement is engineered drainage and the application of excessive amounts of gypsum, sulfur, and good quality water - and the discharge of the sodium laden drainage water.

Because of its lack of structure and vegetation, dispersed soil is very susceptible to erosion. Depending on the location of the CBM water discharge and the drainage course, a normal rain or storm event could easily provide the flow rate and runoff necessary for erosion on a large scale of the already dispersed, saturated, sodic soils. The soil's dispersion takes place through out the profile. So, the erosion will continue to a point where the profile has not been exposed to the sodic water or it reaches a basement pavement structure that cannot be dispersed or eroded, like coarse gravels or bedrock. In any single drainage, the above scenario could take place repeatedly with down cutting and erosion that would continue until the soil profile is completely eroded away and what is left behind is a "V" shaped cut with bedrock in the bottom. Water will also infiltrate within the ephemeral channels and streambanks, which will contribute to increased erosion in the drainages over time. Another long-term effect includes saline seeps that may appear on lower terraces, river banks, and below impoundments where high SAR water flows or is stored. This may result in varying degrees of adverse effects on vegetation, consumers of that vegetation, the soil, and water quality of any streams receiving salts from such seeps. The native species composition in these effected areas will also change. CBM water discharge will have the cumulative effect of encouraging the establishment and proliferation of non-native and noxious weed species like Salt Cedar that thrive and dominate under high sodic/salt conditions.

Development of a sodium hazard usually takes time. Soil tests for SAR or percent exchangeable sodium can detect changes before permanent damage occurs. Proper management can maintain SAR and salinity values at a steady state below threshold levels.

BEST MANAGEMENT PRACTICES AND MITIGATION

Impacts to resources can be reduced through the use of mitigation technologies. Mitigation may include project-scale permitting, active mitigation during construction, protection of water rights, produced water management, and monitoring techniques.

MITIGATION

The impacts to resources that result from surface disturbances can be mitigated by active restoration once construction activities end. There are also laws and regulations designed to protect some resources such as cultural and paleontological resources, Indian Trust Management, wildlife, and lands and realty. Other impacts can be mitigated through technology such as air quality and noise.

CBM production in the Montana PRB will certainly impact a variety of resources including groundwater, surface water, soils, and agriculture. Impacts to groundwater resources may, however, be mitigated through the use of water well agreements, limits placed on discharge and monitoring programs. Furthermore, a predictive model may be helpful as an approximation of future impacts. Groundwater rights will be protected through the use of spring/water well mitigation agreements and an approved monitoring plan to aid in the identification of potentially significant drawdown impacts. Surface water resources can be protected by limiting discharge through alternative management techniques.

Project planning will include protection of adjacent water rights and CBM rights through mitigation agreements and monitoring. Administration of CBM projects is the jurisdiction of the MBOGC with guidance from the MDNRC and the CBM Technical Advisory Committee. A monitoring plan will be required that may involve dedicated monitoring wells or systematic gauging of private water wells.

WATER MITIGATION AGREEMENTS

Water rights and mitigation agreements can be used to protect groundwater wells and springs. Both the MDNRC and the MBOGC advocate the use of agreements in areas surrounding CBM development as a way of protecting surrounding ranchers and farmers from damage from the inevitable drawdown. Water well mitigation agreements will be the cornerstones of CBM development in Montana. The contract simplifies relief for the aggrieved party (usually the landowner) to file claims without need for counsel. The contract further allows the operator to proceed with aquifer pump-down that is necessary for CBM development. If and when groundwater supplies are impacted, the operator will be required to deliver the same quality of water as that being impacted. The operator can then choose the water replacement option that bests suits his operating plan. Currently, CBM operators are required to offer mitigation agreements to residents within at least one-half mile of the edge of development. If any of these wells or springs are impacted, agreements will be offered to land owners one-half mile beyond.

WATER RIGHTS

Water rights in Montana are guided by the prior appropriation doctrine, that is, first in time is first in right. A person's right to use a specific quantity of water depends on when the use of water began. The first person to use water from a source established the first right; the second person could establish a right to the water that was left, and so on. During dry years, the person with the first right has the first chance to use the available water to fulfill their right. The holder of the second right has the next chance. Water users are limited to the amount of water that can be beneficially used. Water rights in Montana are managed by three entities: the Department of Natural Resources and Conservation (DNRC), the Montana Water Court, and the district courts. DNRC administers the portions of the Montana Water Use Act that relates to water uses after June 30, 1973. DNRC trains water commissioners and teaches water-measuring techniques. They also provides technical information and assistance to the Water Court, which is responsible for adjudicating water rights that existed before July 1, 1973. The Water Court decides any legal issues certified to it by DNRC that may arise in connection with permit or change applications, or in disputes filed in the district courts. The district courts can issue injunctive relief while it certifies water right issues to the Water Court for decision. DNRC maintains a central records system for all permits, changes, and certificates issued after June 30, 1973, and for all existing water rights filed as part of the statewide adjudication.

Specific to CBM development in the PRB, the Montana Department of Natural Resources issued a Final Order: “In the Matter of the Designation of the Powder River Basin Controlled Groundwater Area”. The order establishes that a CBM well does not require a MDNR Permit to appropriate water but the order sets out requirements for CBM wells and developments.

PRODUCED WATER MANAGEMENT

CBM water production will vary considerably in volume and quality and must be effectively managed during development. As has been seen in the CX Ranch field, water production rates can be expected to fall during the life of a new CBM field but the applicability of this data to other producing areas of the PRB is unknown. Produced water regulations must allow management alternatives so that costs will be kept low to promote wide CBM development. On the other hand, water management options must protect the full range of environmental resources. The choice of alternatives can depend on economics, regulatory burden, produced water quality, and local geographic conditions. The following are typical produced water management alternatives that are used in other CBM basins and in conventional oil and gas production:

- Discharge to impoundments. As is done in parts of the PRB in Wyoming, produced water can be discharged directly to ponds and tanks. In Montana these ponds require MBOGC permits and if the water is in excess of 15,000 mg/l TDS the pond or impoundment must be lined with an impermeable liner (ARM 36.22.1227). Such discharges will require a general produced water discharge MPDES permit from the MDEQ (ARM 17.30.1341).
- Discharge to surface water. Produced water can be discharged to waters of the state with an appropriate permit from the MDEQ. New discharges are subject to Non-degradation Rules (ARM 17.30.700). These rules prohibit increases in the discharge of toxic and deleterious materials to state waters, unless it is affirmatively demonstrated to the MDEQ that a change is justifiable as a result of necessary economic or social development and will not preclude present and anticipated use of these waters. Discharge rates will be calculated on the basis of the quality of the produced water and quantity and quality of the receiving water.
- Disposal to shallow aquifers. It is possible to dispose of produced CBM water into shallow, drinking water aquifers. For example, produced water could be pipelined to a nearby area where coal aquifers do not produce methane and are not connected to productive coal seams. The produced water could be injected with the required permit from the US EPA Region 8. Injection wells would be described as Class V aquifer recharge wells permitted under 40 CFR 146 Subpart F. If the injectate (CBM water) exceeds primary drinking water standards, the permit may require an aquifer exemption petition to the EPA. Shallow injection has the advantage of preserving the CBM water resource at the same time that surface waters and surface soil is protected.
- Disposal into deep zones. Operators can inject CBM produced water into deeper reservoirs that are not classified as USDWs. Montana contains many of these reservoirs scattered across the state. The reservoirs' ability to accept large volumes of injected water and their depths are highly variable. Deep injection requires a permit from the MOBGC and could require a permit from the US EPA if Indian Tribal Land is involved. Deep injection can be limited by economics if suitable injection zones are too deep or cannot accept sufficient fluid relative to the volume of water produced by CBM development. Deep injection has the advantage of protecting surface water resources but the CBM water resource is lost. In addition, injection wells are dedicated facilities that can be extremely expensive to drill and operate.
- Industrial beneficial uses. Oil and gas and CBM development will require large quantities of water during drilling, completion, and testing. Coal mining can require large volumes of water for dust control, slurry mining, and slurry pipelining. Other industries such as manufacturing and meat processing may have uses that are compatible with CBM produced water.
- Agricultural beneficial uses. Montana ranchers and farmers require large volumes of water to irrigate crops and water livestock. Irrigation uses have a narrow range of acceptable water quality depending upon soil type and crop selection but some reported coal aquifers contain suitable water. Soils and crops have a particular sensitivity to sodium and its concentration relative to calcium and magnesium in the water. Livestock have a somewhat wider range of quality acceptance depending upon the types of animal being raised. Livestock also has sensitivity to other contaminants in the water. Within the planning period, agricultural uses of the produced water from CBM operations may become more prevalent across the state.
- Pre-Disposal treatment. Produced water can be treated prior to being discharged or disposed. Treatment such as reverse osmosis (RO) can be targeted at a single ion such as sodium, rendering the processed water more compatible for a beneficial use. Skid-mounted RO units can be installed near "pod" manifolds or at single high-delivery wells. RO units can be powered by natural gas or electricity including wind turbines. Economics will vary on a site by site basis.

CONCLUSIONS

Development of CBM in the Montana portion of PRB has many complexities that must be analyzed in order to determine how to best manage this resource. The environmental impacts from full development of this resource could potentially pose great risk to the existing environment. These impacts can be limited and controlled through the use of mitigation measures and best management practices. Impacts resulting from activities that cause surface disturbances can be mitigated by active restoration once construction activities end. There are also laws and regulations designed to protect some resources that must be followed. The greatest impact from CBM development results from the production of groundwater that accompanies methane gas production. This produced water will be produced in large quantities to allow for the production of methane and will likely vary in quality depending on the source. The impacts from CBM produced water can be mitigated through conservation, proper disposal methods, and beneficial use. The proper management of produced water will prevent some impacts to other resources such as soil, agriculture and groundwater, and may provide beneficial uses such as dust suppression, irrigation and livestock watering.

REFERENCES

Aubry, A.M., A. McKee, and C. Wehrli. 1998. Soil Gas Survey of the Ferron Sandstone Member of the Mancos Shale, Northern Emery County, Utah. Bureau of Land Management, Utah State Office, Salt Lake City, Utah. June 1998.

Ayers, R.S., and D.S. Westcot. 1985. Water Quality for Agriculture, FAO Paper 29, Rev.1. Rome.

Bauder, J. 1999. Coal Methane Gas and Montana Water Quality. Unpublished document. Extension Soil and Water Quality Specialist, Montana State University. Bozeman, Montana.

Bergantino, R.N. 1980. Hardin Groundwater Sheet MA-2B, Montana Bureau of Mines and Geology.

BLM. 1999a. Groundwater modeling of impacts associated with mining and coalbed methane development in the eastern Powder River Basin, Technical Report to accompany Wyodak Coalbed Methane FEIS.

BLM. 1999b. Wyodak Coalbed Methane Project Final EIS, Buffalo Field Office. October 1999.

BLM. 1999c. Wyodak Coalbed Methane Project Draft EIS, Buffalo Field Office. 1999.

BLM. 2000b. Oil and Gas Development on the Southern Ute Indian Reservation, Draft EIS, October, 2000.

BLM. 2001. Reasonable Foreseeable Development Scenario

Bury, R.B. 1980. What we know and do not know about off-road vehicle impacts on Wildlife. R.N.L. Andrews and P. Nowak, editors. Off-Road Vehicle Use: A Management Challenge. (Univ. of Michigan Extension Service) Michigan League. The University of Michigan, School of Natural Resources. USDA The Office of Environmental Quality.

Ellis, M.S., G.D. Stricker, R.M. Flores, and L.R. Bader. 1998. Sulfur and ash in Paleocene Wyodak-Anderson coal in the Powder River Basin, Wyoming and Montana, Proc. 23rd Internal. Tech. Conf. on Coal Utilization, March 1998.

Ellis, M.S., G.L. Gunther, R.M. Flores, A.M. Ochs, G.D. Stricker, S.B. Roberts, T.T. Taber, L.R. Bader, and J.H. Schuenemeyer. 1999. Preliminary report on coal resources of the Wyodak-Anderson coal zone, Powder River Basin, Wyoming and Montana, U.S. Geological Survey Open-File Report 98-789A.

Flores, R.M. and L.R. Bader. 1999. Fort Union coal in the Powder River Basin, Wyoming and Montana: a Synthesis, in USGS Prof. Paper 1625-A.

Flores, R., Stricker, G., Meyer, J., Doll, T., Norton, P., Livingston, R., Jennings, M. 2001. A Field Conference on Impacts of Coal Bed Methane Development in the Powder River Basin, Wyoming, USGS Open-File Report 01-126.

Glass, G.B., R.W. Jones, and R.H. De Bruin. 1987. Investigation of the Potential for Near-Surface Explosive Concentrations of Methane to Occur in the Rawhide Village Subdivision, Campbell County, Wyoming: Geological Survey of Wyoming Report for the Wyoming Department of Environmental Quality (unpublished), 7p., 3 plates.

Gray, I. 1987. Reservoir Engineering in Coal Seams: Part 1 – The Physical Process of Gas Storage and Movement in Coal Seams, SPERE, pp. 28-34, February, 1987.

Heffern, E.L. 1999. Methane Seepage and Coal Fires. Unpublished Report for Wyodak CBM Project EIS. Prepared for BLM Buffalo Field Office, Buffalo, WY.

Jones, R.W., R.H. De Bruin, and G.B. Glass. 1987. Investigations of Venting Methane and Hydrogen Sulfide Gas at Rawhide Village, Campbell County, Wyoming, in Rawhide II Project Report, Appendix I, Geology: Wyoming Department of Environmental Quality, Cheyenne, Wyoming (unpublished), 23p., 12 plates.

Leythenhaeuser, D., and Welte, D. 1969. Relation between distribution of heavy n-paraffins and coalification in carboniferous coals of the SAAR district, Germany. In P. Schrenk and I. Havenaar (eds.), Advances in Organic Geochemistry, 1968. NYC, Pergamon Press, pp. 429-442.

MBMG 2001. Montana Bureau of Mines and Geology, Groundwater Information Center Database, http://mbmggwic.mtech.edu/ March 2001.

MBOGC Montana Bureau Of Oil and Gas Database, April 2001.

Montana Bureau of Mines and Geology. 2001. Water well database, maintained by the Montana Bureau of Mines and Geology.

McLellan, M.W., Biewick, L.R.H., Molnia, and Pierce, F.W. 1990. Cross sections showing the reconstructed stratigraphic framework of Paleocene rocks and coalbeds in the northern and central Powder River Basin, Montana and Wyoming. USGS Misc. Invest., Map I-1959-A.

Miller, W.R. 1981. Water resources of the Southern Powder River area, Southestern Montana, MBMG, Memoir 47.

Mongomery, S.L., D.E. Tabet, and C.E. Barker. 2001. Upper Cretaceous Ferron Sandstone: major coalbed methane play in central Utah. A.A.P.G. Bull v. 85, pp. 199-219.

MSU 2001. When is Water Good Enough for Livestock, www.montana.edu/wwwpb/ag/baudr146.html

Nelson, C.R. 2000. Coalbed Methane Potential of the US Rocky Mountain Region, Gas Tips, vol. 6, no. 3, pp. 4-12.

Noble, R.A., R.N. Bergantino, T.W. Patton, B. Sholes, F. Daniel, and J. Schofield 1982. Occurrence and characteristics of groundwater in Montana, MBMG 99.

Peacock, K., A. Anderson, J.R. Oakleaf, and S.P. Gloss. 1997. A Study of Techniques to Assess Surface and Groundwater Impacts Associated with Coalbed Methane and Surface Coal Mining: Little Thunder Creek Drainage, Wyoming, Final Report prepared by Wyoming Initiative Laboratory. 307pp.

Redstone Gas Partners. 2000a. Request for Authorization of Class V Injection Wells, Section 2 – T9S – R39E, Bug Horn County, MT, application to US EPA Region VIII, November 2000.

Redstone Gas Partners. 2000b. Application for Permanent Spacing, Docket No. 155-2000, MBOGC application, December 14, 2000.

Rice, C.A., M.S. Ellis, and J.H. Bullock. 2000. Water co-produced with coalbed methane. USGS OF Report 00-372.

Roberts, S.B., G.L. Gunther, T.T. Taber, A.M. Ochs, D. Blake, M.S. Ellis, G.D. Stricker, E.M. Wilde, J.H. Schuenemeyer, and H.C. Power. 1999a. Decker Coalfield, Powder River Basin, Montana: geology, coal quality, and coal resources, in USGS Prof. Paper 1625-A.

Roberts, S.B., E.M. Wilde, G.S. Rossi, D. Blake, M.S. Ellis, G.D. Stricker, A.M. Ochs, G.L. Gunther, J.H. Schuenmeyer, and H.C. Power. 1999b. Ashland Coalfield, Powder River Basin, Montana: geology, coal quality, and coal resources, in USGS Prof. Paper 1625-A.

Selvig, W.A. and W.H. Ode. 1953. Determination of Moisture-Holding Capacity (Bed Moisture) of Coal for Classification by Rank: U.S. Bureau of Mines Report of Investigations 4968, 10p.

Trombulak, S.C. and C.A. Frissell. 2000. “Review of ecological effects of roads on terrestrial and aquatic communities.” Conservation Biology. 14:18-30.

Tudor, M.S. 1975. Geologic exploration and development of coal in the Sarpy Creek area, Big Horn County, Montana, in J. Doroshenko, W.R. Miller, E.E. Thompson, Jr., J.H. and Rawlins, eds., Energy Resources of Montana: Montana Geological Society 22nd Annual Publication, pp. 159-164.

USDI and USDA. 2001. Off-highway vehicle environmental impact statement and proposed plan amendment for Montana, North Dakota and portions of South Dakota. U.S. Department of the Interior, Bureau of Land Management, Montana State Office and U.S. Department of Agriculture, Forest Service, Northern Region.

USGS. 1986b. Potentiometric-surface Map of the Wyodak-Anderson Coal Bed, Powder River Structural Basin, Wyoming, 1973-84. USGS Water-Resources Investigations Report 85-4305, Scale 1:250,000, 1 sheet. Prepared by Pamela B. Daddow in cooperation with the BLM. Cheyenne, WY.

USGS. 1988. Cumulative Potential Hydrologic Impacts of Surface Coal Mining in the Eastern Powder River Structural Basin, Northeastern Wyoming. USGS Water-Resources Investigations Report 88-4046. Prepared by L.J. Martin, D.L. Naftz, H.W. Lowham, and J.G. Rankl in Cooperation with the Wyoming Department of Environmental Quality and the U. S. Office of Surface Mining, Cheyenne, WY.

USGS 1995. Estimated Use of Water in the United States in 1995, USGS Circular 1200, 1996.

Van Voast, W. and Thale, P. 2001. Anderson and Knobloch Coal Horizons and Potential for Methane Development, Powder River Basin, MBMG Map 60, 2001.

Williams, B. 2001. Personal communication between Dr. Langhus and Mr. Williams, Vice President of Redstone Gas Partners LLC, March 23, 2001.